PERICARP THICKNESS, TENDERNESS, AND FREEZE-DRYING OF SUPER-SWEET MAIZE

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ABSTRACT

Mass selection for tenderness was conducted on the variety 'Hawaiian Super-sweet No. 9' corn which was found to vary widely in tenderness. Selection was carried out on a 10 % selection intensity using criteria of pericarp thickness and bite-test. Selection was carried out for 3 cycles by pericarp thickness measurements and for 4 cycles by bite-testing. All cycles of selection were evaluated by both bite-testing and by pericarp thickness measurements. In the first cycle of selection where pericarp thickness and bite-test measurements were taken on the same ear, a significant product moment correlation coefficient (r = 98%) was found between bite-test scores and pericarp thickness measurements. Pericarp thickness evaluation on the cycles of selection indicated that pericarp thickness decreased by a greater margin when selected for by pericarp thickness than by bite-testing. However, when all cycles of selection were evaluated by bite-testing, the bite-test scores dropped more significantly for selection by bite-testing than by pericarp thickness measurements. There was no significant interaction between the germinal and abgerminal positions measured on the pericarp and the cycles of selection.

A generation mean analysis involving crosses between thick and thin pericarped parents was conducted to evaluate the genetics of pericarp thickness. Additive and dominance gene effects were significant in determining pericarp thickness with additive effects being larger. The narrow sense heritability estimate was 51%. The average number of effective factors ranged from 1 through 7. No significant difference in pericarp thickness was found between su and + kernels segregating on the F1 ears.

Nine mainland sweet corn hybrids (Jubilee, Stylepak, Bonanza, NK51036, GCB (N), GCB (T), Midway, and Gold Winner) and a tropical sweet corn hybrid (H68) were evaluated at the locations of Waimanalo and Lalamilo to assess the effect of temperature on pericarp thickness. Generally, all except 3 hybrids (Iobelle, GCB (N), and GCB (T)) behaved similarly at both locations. Pericarp thickness was also observed to be lower at sweet corn stage than at maturity.

A survey of pericarp thickness on 85 different races of maize was conducted. Some of the races that were duplicately sampled differed only by a second descriptive name for ear characteristics. In some cases, these were similar in pericarp thicknesses while in other cases they were different in pericarp thicknesses. Some of the same races maintained in different seed lots were dissimilar in pericarp thickness. A wide genetic variation in pericarp thickness occurred in the group of races analyzed. Pericarp thickness ranged from 35.8 to 124.4 microns.

Two experiments were conducted to evaluate the influence of various endosperm genotypes on the pericarp thickness. In the first experiment, 15 mutants backcrossed to CM104 were evaluated for pericarp thickness. Generally, all mutants highly backcrossed into CM104 were of similar pericarp thicknesses. However, the sh2 mutant seemed to be linked to thick pericarps. Otherwise, there is no evidence of the underlying endosperm affecting pericarp thickness. In the second experiment, 8 inbred lines and their o2 counterparts were analyzed for pericarp thickness. No consistency was found in the data. Half of the comparisons indicated no differences between the + and o2 lines whereas significant differences occurred in the other half.

A series of three freeze-drying experiments were conducted on 'Hawaiian Super-sweet No. 9' to improve the methodology and quality of the freeze-dried product. These were: 1) blanched versus unblanched kernels, 2) maturity preferences, and 3) increasing concentrations of brine solution applied to the kernels prior to freeze-drying. The first two experiments were evaluated by sensory panelists on the quality of appearance and flavor. The last experment was evaluated by flavor only. Blanched and unblanched kernels were of similar flavor, but the blanched kernels were rated higher in appearance. Thus, they were selected over unblanched kernels. A harvest date of 25 days after pollination was selected as the optimum maturity by criteria of appearance and flavor. No treatment of the kernels with brine was found to be most practical in preparing a commercial freeze-dried super-sweet corn product.

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CHAPTER ONE

1. STUDIES OF TENDERNESS AND PERICARP THICKNESS IN MAIZE

1.1 INTRODUCTION

Successful marketing of sweet corn requires that four general quality factors governing the salability of the product be considered--appearance, palatability, stability, and consistency. Of these factors, the major criterion by which consumers distinguish high quality sweet corn from low quality sweet corn is its palatability, although its appearance is equally important as a first impression. The palatability of sweet corn is determined by tenderness, flavor, and maturity.

Tenderness was considered to be the most important of all factors determining the palatability of sweet corn (Culpepper and Magoon, 1927), therefore, the incorporation of tenderness into sweet corn hybrids and varieties has been one of the major concerns of a sweet corn breeder. Tenderness of sweet corn was determined to be predominantly affected by pericarp thickness and maturity. Evaluations of tenderness can be conducted through two general procedures which are either quantitative, i.e., measuring pericarp thickness (Bailey and Bailey, 1938) or qualitative, i.e., bite-testing by sensory panels. Quantitative methods are generally precise, but time-consuming and not necessarily accurate, whereas organoleptic methods are rapid, accurate, but less precise. A method which is most efficient in terms of accuracy, precision, and speed would be desirable in the process of breeding tenderness into sweet corn varieties and hybrids. A modified micrometer method of

measuring pericarp thickness (Helm and Zuber, 1972a) and a bite-test were used to determine tenderness in a mass selection study on tenderness. These methods were evaluated for their efficiency in determining tenderness and a correlation between these two methods was derived.

The genetics of pericarp thickness have been studied by several researchers (Richardson, 1960; Helm and Zuber, 1972a; and Ho et al. 1975) who found high heritability estimates for this trait and dominant genes for thin pericarps. However, studies by Ho et al. (1975) and Helm and Zuber (1972a) resulted in different types of epistatic gene effects. A generation mean analysis was conducted to determine a heritability estimate and the gene effects for pericarp thickness from generations derived from crosses between sweet and field corn inbred lines with thin and thick pericarps respectively. The results of this and previous studies on the genetics of pericarp thickness can provide breeders with information necessary in determining a breeding method most efficient in altering this trait.

Three additional experiments were conducted to examine the behavior of pericarp thickness of some of the major commercial sweet corn varieties at two different locations, the variability of pericarp thickness in some of the races of maize, and the effects of the underlying endosperm on pericarp thickness.

1.2 LITERATURE REVIEW

1.2.1 Quality of Sweet Corn

Early research on quality of corn was primarily devoted to the quality of canned sweet corn. Due to the rising popularity of the canned sweet corn product, there was a need to understand exactly what constituted quality in order to promote manufacture and sales of the product. Culpepper and Magoon (1927) were the first to determine the factors affecting the quality of canned sweet corn. These factors were listed as: 1) the degree of tenderness or toughness of the pericarp; 2) the nature of the polysaccharides present and the ratio of water soluble to total polysaccharides; 3) the sugar content; and 4) the compactness with which the polysaccharides are laid down in the endosperm. Other research concentrated on developing quality in sweet corn which was to be consumed in the fresh state (Jenkins and Sayre, 1936; Kramer and Guyer, 1949; Barton, 1954; and Kerr, 1961). Quality was generally defined in terms similar to that of Culpepper and Magoon (1927), with emphasis on succulence or moisture percentage, quantity and toughness of the pericarp, and flavor. Kramer and Guyer (1949) emphasized that the appearance of the fresh sweet corn is equally important, because consumers generally purchase it on the basis of the appearance of freshness.

1.2.2 Factors Determining Tenderness

Culpepper and Magoon (1927) considered tenderness of the kernels to be the most important factor determining quality. Several factors

affecting the degree of tenderness were reported: quantity and toughness of the pericarp, endosperm differences, and maturity of the kernels.

The degree of toughness and the quantity of the pericarp constitutes the major criteria by which tenderness is determined (Culpepper and Magoon, 1927). At a given stage of maturity, sweet corn varieties with the lowest puncture readings were in general those with the thinnest pericarps, which suggests that varieties with thin pericarps are more tender (Bailey and Bailey, 1938). Considering the quantity of the pericarp, several researchers reported that the measurement of percentage pericarp is a dependable means by which tenderness may be determined (Kramer and Guyer, 1949; Gould et al., 1951; Geise, 1952; and Twigg et al., 1956). Examining both factors, Wolf et al. (1969) found that a close correlation exists between percent pericarp by weight and pericarp thickness.

Progressively higher puncture meter readings, which indicate toughness of the kernels, occur during kernel maturation and have been attributed to increasing pericarp toughness and endosperm compaction. Culpepper and Magoon (1924) reported that increasing maturation of the kernels was accompanied by an increase in the resistance of the kernels to puncture. All strains they had tested followed the same trend towards a rapid rise in toughness (puncture meter scores) during kernel maturation. Similarly, Doxtator (1937) found a high negative correlation ($r = 0.98$) between puncture-test readings and moisture percentages at different stages of harvests. Using the same testing procedure, Bailey and Bailey (1938) reported that increased puncture-test readings occurred with increasing kernel maturation.

1.2.3 Anatomical and Morphological Characteristics of the Pericarp

The pericarp is of maternal origin and is the outermost structural part of the kernel. It covers the kernel completely except for the base which is covered by the tip cap. Wolf et al. (1952b) observed that the pericarp could be subdivided into four somewhat distinct portions. Starting from the outermost layer, they are the epidermis, mesocarp, cross cells, and tube cells. The mesocarp was reported to be the major constituent of the pericarp. The pericarp comprised slightly more than 5% of the kernel by weight and was approximately equal to the amount of bran in the hybrid dent corn they had studied.

Wolf et al. (1952b) also observed differential thickness of the pericarp over the whole kernel. The pericarp was found to be much thicker at the base of the kernel than at the central and upper regions. The thinnest portion was found to be over the crown. The abgerminal side consisted of an average of 22 cells which was not significantly greater than the average of 20 cells at the germinal side. They concluded that endosperm compaction differences over different parts of the kernel were largely responsible for the variation in pericarp thickness rather than the variations in cell numbers. The pericarp was also observed to be slightly thicker at the abgerminal side of the kernel than at the germinal side, a condition also observed by Banafunzi (1974).

1.2.4 Developmental Characteristics of the Pericarp

Morphological aspects of pericarp development were studied by Haddad (1931), Randolph (1936), Bailey and Bailey (1938), and Richardson

(1960). In general, they observed that actual pericarp thickness increased in the early stages of development and then decreased progressively thereafter due to resorption of the inner pericarp cells.

Using a microscopic method to measure pericarp thickness, Haddad (1931) studied two inbred lines of sweet corn and their F1 hybrid. Pericarp thickness of the inbred lines and the hybrid increased until the ten- and fifteen-day stages respectively, after which they steadily decreased in thickness while approaching maturity. Corresponding research was conducted by Bailey and Bailey (1938) on sweet corn varieties, inbreds, and hybrids using micrometry and microscopic methods. They observed decreasing pericarp thickness with advancing maturity until 31 days after pollination. Randolph (1936) found that pericarp thickness increased up to 9 to 12 days after pollination in the basal region. This difference was said to be due to the disintegration of the middle portion of the pericarp which took place earlier at the crown than at the base. Soon after, lateral growth activity ceased and the middle regions disintegrated along with lateral compression of the pericarp tissue which resulted in a gradual decrease in pericarp thickness until physiological maturity was reached. All of these studies indicated that during the decrease in pericarp thickness, the inner cells are the first to become resorbed, compacted, disintegrated, and disorganized. As development progresses, the inner pericarp is crushed against the outer pericarp wall and becomes completely resorbed at the final stage of kernel development. This was considered due to the enlargement of the endosperm. The outer pericarp was described to become progressively thinner and its cell walls progressively thicker at the later stages of

development approaching maturity, thus explaining the increasing toughness of the pericarp. Randolph's study (1936) also indicated that the continuing elongation of the pericarp from the base to the crown and the increase in circumference of the kernels occurs until the kernels are morphologically mature and the endosperm ceases to expand.

Richardson (1960) studied crown portions of popcorn pericarp at the later stages of maturity not looked into by previous researchers. He determined that pericarp thickness decreased with increasing maturation of the kernels; minimum thickness was at 32% moisture, i.e., physiological maturity. He suggested that this decrease in pericarp thickness was caused by stretching from the enlargement of the endosperm in addition to the loss of water and decreased succulence of the pericarp tissue. After minimum thickness has been reached, a reversion towards thicker pericarps occurred and pericarp thickness gradually increased until about 24 days after physiological maturity. Although no lignin analysis was reported, Richardson (1960) attributed this occurrence to the lignification of the pericarp tissue. Randolph (1936) previously found through the use of a stain specific to lignin that the cell walls of the mature pericarp are highly lignified. The thickening trend was also observed to continue to a limited extent after the ears were harvested since pericarp thickness measurements immediately after harvest were less than those taken after drying (Richardson, 1960). This study suggested that the best way to minimize the effect of kernel maturation on pericarp thickness is to wait until approximately three weeks after physiological maturity of the ears when pericarp thickness stabilizes.

Helm and Zuber (1970) studied dent corn inbred lines using micrometry and found no significant difference in mature pericarp thickness from excised pericarps when the ears were harvested at 15% or 30% moisture. Their results were not similar to that of Richardson's (1960) who found significant differences between pericarp thickness at various harvest stages after physiological maturity. However, Richardson measured crown tissues whereas Helm and Zuber measured thicknesses around the side of the kernels and discarded the crown pericarp tissue. The crown tissue was discarded because it was difficult to measure in dent corn since it is wrinkled and distended at maturity. Popcorn, in contrast, has a smooth, round crown tissue which facilitates measurement. Helm and Zuber (1970) stated that there may have been differences in the thicknesses of crown pericarp tissues in dent corn at various harvest stages, but results comparable to Richardson's study of popcorn would be difficult to obtain.

Despite the thinning trend of the pericarp, studies have indicated that the quantity of pericarp increases with advancing maturity. Groszmann and Sprague (1948) measured the weights of the pericarps periodically for a period of 52 days after pollination and found that pericarp weights increased somewhat rapidly during the early stages of development and gradually during the later stages of development. Similarly, Barton (1954) found that there is greater percent pericarp by weight as the kernels approach maturity.

1.2.5 Methods of Determining Tenderness

Tenderness may be determined quantitatively or qualitatively. There

are three general quantitative criteria by which tenderness may be determined. These are: 1) grams pressure required to puncture kernels (Rudnick and Bakke, 1920); 2) quantity of the pericarp (Kramer and Guyer, 1949); and 3) pericarp thickness measurements in microns (Bailey and Bailey, 1938). Quantitative and organoleptic methods include bite-testing by sensory panels or by a trained individual.

All of these criteria for testing tenderness require that maturity be held constant for accurate comparisons. Also, sampling of the kernels on the ears should be uniform since kernels on the middle portion of the ears mature earlier (Culpepper and Magoon, 1924).

Among the earliest quantitative methods of determining tenderness was a puncture meter designed to test sweet corn (Rudnick and Bakke, 1920). This test indicates the grams of pressure needed to penetrate the kernels using a constant size needle. A modified puncture meter was developed by Culpepper and Magoon (1924) to give simple, rapid, and direct readings; it is the model for modern puncture meters. Normally this device measures the resistance of the pericarp and the endosperm to puncture. However, a procedure to measure the resistance of the pericarp to puncture independently of the underlying endosperm tissue was developed by Andrew et al. (1944). This procedure required that the pericarp be removed prior to testing.

Kramer and Guyer (1949) developed a method to measure the percent of pericarp. Kernels were blended in a Waring blender and aliquots of the slurry were washed through a screen. The screen and the pericarp were dried and weighed, and the screen weighed again without the pericarp to determine the quantity of pericarp. Various modifications of the

method were reported (Gould et al., 1951; Geise, 1952; and Barton, 1954), which were the use of a tarred screen, whole samples instead of aliquots, finer screen, and drying for longer periods of time. Kramer (1952) evaluted methods of determining percent pericarp and found that Kramer and Guyer's method (1949) and Geise's method (1952) were quite accurate in determining tenderness (through correlations with human evaluations). Another method of determining percent pericarp was used by Groszmann and Sprague (1948) and by Wolf et al. (1956), where the entire pericarp was removed from the kernels and both of these tissues were dried to determine the moisture content. The amount of pericarp was reported on a dry weight basis as percentage of total kernel weight.

Two methods which are often used to measure pericarp thickness are micrometry and microscopy. Measurement of pericarp thickness by micrometry was first outlined by Wolf et al. (1969) and was modified by Helm and Zuber (1972). After removing a strip of pericarp from the kernels, the pericarps were placed into a water-glycerol solution (by volume), evacuated, and left to equilibrate in a constant environment. Pericarp thickness was then taken with a micrometer.

Wolf et al. (1969) developed an accurate microscopic method of measuring pericarp thickness. Kernels were soaked in water, frozen and sectioned longitudinally in a cryostat. Sections were stained with Oil-Red-O in propylene glycol. Stained sections were mounted in propylene gylcol:water solution and measured with a microscope equipped with a calibrated ocular micrometer. Other methods were outlined by previous researchers (Haddad, 1931; Bailey and Bailey, 1938; and Richardson, 1960).

Wolf et al. (1969) evaluated the microscope, micrometer, and percent

pericarp methods. Pericarp thickness by the microscope method and by the micrometer method were found to be highly correlated by the Spearman's rank correlation coefficient (r_{sp} = 0.85). Pericarp thickness for the microscope method as compared to the micrometer method was reported to be slightly higher due to compression of the pericarp from the micrometer plunger. Pericarp thickness and weight were also found to be highly correlated, r_{sp} = 0.84 for the microscope method and r_{sp} = 0.72 for the micrometer method.

1.2.6 Genetics of Pericarp Thickness

Metaxenia:

No metaxenia effect on pericarp thickness has been found on mature corn kernels by a number of researchers (Groszmann and Sprague, 1948; Helm et al., 1970; and Helm and Zuber, 1972b).

Studies on high oil and popcorn lines by Groszmann and Sprague (1948) indicated that in reciprocal crosses no significant differences occurred between pericarp weight of hybrids and their respective maternal parents. Experiments by Helm et al. (1970) on various endosperm mutants showed that kernels on ears segregating for the various types of mutants had similar pericarp thicknesses. Helm and Zuber (1972b) conducted a comprehensive study of metaxenia effect of pericarp thickness. Dent corn inbred lines having different pericarp thicknesses were either self pollinated or pollinated with a pollen mixture. The different types of F1 kernels were identified by endosperm color differences. Pericarp thickness measurements indicated a striking lack of metaxenia effect on the pericarp tissue.

On the other hand, Andrews et al. (1944) observed metaxenia effect on pericarp tissue for resistance to puncture in studying sugary and nonsugary kernels on the same ear. This test was conducted after the pericarps were removed from the kernels so that the underlying endosperm had no effect on the puncture readings. The sugary kernels were reported to have significantly less resistance to puncture (54gm pressure) than nonsugary kernels (75gm pressure).

Inheritance of Pericarp Thickness:

The mode of inheritance of pericarp thickness has been described by Richardson (1960) for popcorn, Helm and Zuber (1972a) for Corn Belt dent lines, and by Ho et al. (1975) on northern Corn Belt inbred lines.

Richardson (1960) conducted a study involving 5 inbreds crossed in all possible combinations, however, no statistical analysis for a diallele design was presented. He reported that the inheritance of pericarp thickness in popcorn may be due to a single dominant gene with a modifier complex responsible for the production of thin pericarps. Thinner pericarps which were observed on the hybrids were said to be caused by the greater enlargement of the endosperm which causes increased stretching of the pericarp tissue. Richardson (1960) also observed that large differences in pericarp thickness occurred between lines presumed to carry the same dominant gene and attributed it to differences in the modifier gene complex controlling pericarp thickness. In agreement, Tracy et al. (1978), who studied crosses between sweet corn and teosinte, observed that pericarps from the F1 hybrids were as thin as the thin-pericarped teosinte parent. All of the F1's they had

tested had similar pericarp thicknesses regardless of the thicknesses of the sweet corn parent.

Conversely, studies by Helm and Zuber (1972a) and Ho et al. (1975) concluded that the inheritance of pericarp thickness is quantitative in nature. Both studies, using analysis 2 of Eberhart and Gardner (1966), reported significant line effects, line heterosis, and specific line heterosis with line effects being of a larger magnitude. This suggested that large amounts of additive genes control pericarp thickness. Both studies also found substantial amounts of negative average heterosis indicating heterosis for thin pericarps. High narrow sense heritability estimates were obtained in each of these studies through regression of offspring on midparental values. Helm and Zuber (1972a) reported an estimate of 80% which corresponded well with the 72% estimate obtained by Ho et al. (1975). These high narrow sense heritability estimates indicated that selection for a desired pericarp thickness can be very feasible. The covariance of the offspring in each parental array with the nonreccurring parent (Wr) on the variance of offspring of each parent (Vr) led Ho et al. (1975) to conclude that thin pericarps in their crosses were generally controlled by dominant genes and thick pericarps controlled by recessive genes. This suggested that selection for thin pericarps may result in greater progress than selection for thick pericarps.

Selection for Pericarp Thickness and Tenderness:

Selection for tough and tender kernels was carried out by Banafunzi (1974) through a bite-test procedure. Upon selection, the ears were divided into two groups designated as tender and tough. Ears

that were selected for tenderness produced kernels that were lower in germination than those selected for toughness. He also selected for both thick and thin pericarps in the tender ear group from the bite-test selection through the use of the micrometer method of Helm and Zuber (1972a). Similar to the bite-test, poorer germination occurred for thin- rather than for thick-pericarped kernels which were related to tender and tough kernels respectively (Bailey and Bailey, 1938). This base population was divided into two groups: kernels with thick pericarps (86-108 microns) and kernels with thin pericarps (52-66 microns). After one cycle of selection for thick and thin pericarps, thick pericarp measurements ranged from 74-120 microns (mean = 91.6 microns) and measurements for thin pericarps ranged from 76-111 microns (mean = 87.6 microns). After cycle two, the mean for thin pericarps dropped to a thickness of 74.2 microns with a range of 54-108 microns. Selection for thick pericarps was carried out for one cycle of selection only. The results of this study suggest that selection for thin pericarps can result in favorable genetic advance.

1.3 MATERIALS AND METHODS

1.3.1 Pericarp Thickness Measurements

A modified version of the micrometer method described by Helm and Zuber (1972a) was used to measure all pericarp thicknesses in the following experiments.

1. Each ear was sampled uniformly by removing six contiguous kernels on neighboring rows from the center of each ear. Five of the six kernels were measured for pericarp thickness.

2. The kernels were soaked in deionized water for about 20 hours at room temperature (25C) or in the reefer for longer storage (10C).

3. The crown and tip cap portions of each kernel were removed with a razor blade and the pericarps were slit along the edge of each kernel and peeled off with tweezers. The result was a rectangular strip of excised pericarp with a germinal and an abgerminal face.

4. The excised pericarps were placed in a 2:1 water:glycerin (by volume) solution and evacuated in a vacuum dessicator. After evacuation, they were allowed to stand for 20 hours at room temperature (25C).

5. The pericarps were blotted dry by placing them between two hand towels and rolling a heavy bottle over the towels. The dried pericarps were then placed in an equilibrium environment of about 25C and 50% relative humidity for about 24 hours before measuring thickness.

6. While measuring thickness, the few pericarps with remaining aleurone layer or loose inner pericarp were scraped off with the

thumbnail to ensure uniformity. Pericarp thickness was read directly in microns with an Ames Model #56212 micrometer at two positions, the center of the germinal and abgerminal portions of the pericarp.

1.3.2 Selection for Pericarp Thickness and Tenderness

The material used in this experiment was the variety 'Hawaiian Super-sweet No. 9' which was found to vary widely in tenderness through preliminary bite-tests. Mass Selection was carried out on a 10% selection intensity for tenderness using the two criteria of bite-test scores and pericarp thickness measurements. Thus, both qualitative and quantitative criteria were used to evaluate tenderness.

A large population of approximately 10,000 plants was initially planted to ensure wide genetic variation. Four hundred plants were selected throughout the field on the basis of disease resistance, stalk strength, brace roots, low ear position, and overall plant vigor. Subsequent population sizes were on the order of about 2,000 plants per cycle.

Possible errors arising from differing maturities between plants were minimized by covering the earshoots prior to silking, cutting the silks back for uniform pollination of each ear, and removing the shoot-bags simultaneously on one day to allow even pollination of the ears. It was speculated that differences in pericarp thickness measurements could arise from maturity differences prior to pollination. For the first cycle of selection only, a correlation between pericarp thickness and bite-test scores was derived and a test for maturity differences of the unpollinated ears and its effect on pericarp thickness was conducted. Ears were labeled (on the shootbags) as "early" for silks

about 4 inches long, "medium" for silks about 2 inches long, and "late" for silks about 1 inch long or less at the time the silks were cut back. When the ears were uncovered for pollination, the shootbags were numbered from 1 to 400 and left stapled to the stalks of the plants for recognition after the ears were evaluated.

The bite-test was conducted at approximately 22 days after pollination (late sweet corn stage), when toughness of the kernels is slightly greater than at prime sweet corn stage to ensure selection of only the most tender ears. The top half of the ears were removed for bite-testing, leaving the bottom half of the ears to mature for seed production. The removed ear-halfs were bite-tested near the cut end and scored on a hedonic scale of 5, with 1 being the most tender and 5 being the toughest. The bite-tested ear-halfs were then labeled with a bite-test score, a relative maturity rating, and the plant number. After testing, the ear-halfs were dried for measurements of pericarp thickness.

After evaluating pericarp thickness, 20 ears rated 1 or 2 in the bite-test were selected for cycle 1 of the bite-test selection criterion. There were only 7 ears with a bite-test score of 1, whereas there were 73 ears rated as 2. Therefore, to ensure selection of the most tender ears, those with the thinnest pericarps were selected from the ears rated as 2. Likewise, 20 ears with the thinnest pericarps were selected for cycle 1 of the pericarp thickness selection criterion. Both of these groups were planted out as two separate isolated populations for future selection. Subsequent cycles from the bite-test group were selected for by the bite-test criterion only, and subsequent cycles from the pericarp thickness group were selected for by pericarp thickness only. Future

cycles of the pericarp thickness selection were conducted on mature ears dried in the field. Shootbags were stapled on to the stalks of the plants and labeled with a number to identify the ears to be evaluated. At harvest, the shootbags were secured to the ears with a rubber band for identification.

For the first two cycles of the bite-test selection, the ears were cut in half for evaluation. This was unsatisfactory since few seeds for the subsequent cycle and the final evaluation could be harvested. Therefore, for cycles 3 and 4, the method of Kerr (1961) for bite-testing was adopted. The husks were pulled down and the ears were bite-tested with the ears still on the stalk. On the selected ears, the husks were pulled back up, covered with a pollination bag and left in the field to mature and dry.

Four cycles of selection were carried out for lower bite-test scores and three cycles were carried out for lower average pericarp thickness measurements. These will be referred to hereafter as B1, B2, B3, B4, and P1, P2, P3 respectively. The initial population will be referred to as C0.

The final evaluation of all eight cycles of selection (C0, B1, B2, B3, B4, P1, P2, and P3) was set up as a randomized complete block design containing 10 replicates of single 20 hill plots for each cycle. The ears were subject to uniform pollination and generally 10 ears were sampled per plot. In some plots, fewer samples were taken due to poor germination and post bite-test decay in several of the ears. The ears of all eight cycles were subject to evaluation by both the bite-test and pericarp thickness measurements to compare the results of selection by

bite-test on selection by pericarp thickness and vice versa. Bite-testing of 200 ears was done on two separate days with a one day interval in between.

1.3.3 Genetics of Pericarp Thickness: Generation Mean Analysis

Two parents (AA8 and 677a) with thin pericarps were crossed with four parents (CI21E, B68, B37, and H55) with thick pericarps to evaluate the genetics of pericarp thickness. All parents were highly inbred. Populations of F1, F2, and backcrosses (B1 and B2) were derived. P1 and P2 refer to parents of thin and thick pericarps respectively. B1 and B2 refer to the backcross of the F1 to P1 and P2 respectively.

Each set of populations was planted in a randomized complete block design with two replications. However, the second replication was lost and the sample size was limited for each generation. The number of rows planted per generation was 3 for P1, P2, and F1, 4 for B1 and B2, and 7 for the F2. Each row contained 20 hills with one plant per hill. The plants were allowed to open pollinate and the ears were harvested at maturity. Samples consisted of 30 ears for P1, P2, and F1, 40 ears for B1 and B2, and 70 ears for the F2 generations. Data on each ear was taken by the method described in Section 1.3.1. Ear means were used in all subsequent analyses.

With the assumption that epistasis and linkage were absent, estimates of the additive, dominance, and environmental variances were calculated by the following formulas, where the phenotypic variance summates all three:

$$V_A = 2VF_2 - (VB_1 + VB_2)$$

$$V_D = VF_2 - (V_A + V_E)$$

$$V_E = (VP_1 + VP_2 + VF_1)/3$$

Narrow sense heritability was calculated by the conventional formula: $nh^2 = V_A/(V_A + V_D + V_E)$

and by Warner's (1952) formula:

$$nh^2 = [2VF_2 - (VB_1 + VB_2)]/VF_2$$

The conventional formula for calculating broad sense heritability is: $bh^2 = (V_A + V_D)/(V_A + V_D + V_E)$

Three other methods of calculating broad sense heritability summarized by Grami et al. (1977):

$bh^2 = (VF_2 - \sqrt[2]{VP_1 \times VP_2})/VF_2$ (Mahmud and Kramer, 1951)

$bh^2 = [VF_2 - \frac{1}{2}(VP_1 + VP_2)]/VF_2$ (Briggs and Knowles, 1967)

$bh^2 = [VF_2 - \frac{1}{4}(VP_1 + VP_2 + 2VF_1)]/VF_2$ (Lawrence & Jinks, 1973)

The minimum number of effective factors controlling pericarp thickness was estimated by:

1) Castle-Wright formula (Grami et al., 1977)

$$k = (\overline{P_1} - \overline{P_2})^2/8(VF_2 - VF_1)$$

2) Weber's formula (Grami et al., 1977)

$$k = (\overline{P_1} - \overline{P_2})^2/8[VF_2 - (VP_1 + VP_2 + VF_1)/3]$$

3) Weber's formula (Grami et al., 1977)

$$k = (\overline{P_1} - \overline{P_2})^2/8(VF_2 - \sqrt[3]{VP_1 \times VP_2 \times VF_1})$$

4) Sewall Wrights formula (Grami et al., 1977)

$$k = (0.75 - h + h^2)(\overline{P_1} - \overline{P_2})^2/4(VF_2 - VF_1)$$

where $h = (\overline{F_1} - \overline{P_1})/(\overline{P_2} - \overline{P_1})$

The A, B, C and the joint scaling tests were conducted by the

methods outlined by Mather and Jinks (1971) and by Rowe and Alexander (1980) respectively, to assess the adequacy of the additive-dominance model with no epistasis. Aspects of the additive-dominance model are also elaborately described by Warner (1954) and by Allard (1960).

The values of A, B, and C should be equal to 0 within the limits of the sampling error if no epistasis is present. The values of A, B, and C are solved by the following formulas:

$$A = 2\overline{B1} - \overline{P1} - \overline{F1}$$

$$B = 2\overline{B2} - \overline{P2} - \overline{F1}$$

$$C = 4\overline{F2} - 2\overline{F1} - \overline{P1} - \overline{P2}$$

The variances of A, B, and C are:

$$V_A = 4V_{B1} + V_{P1} + V_{F1}$$

$$V_B = 4V_{B2} + V_{P2} + V_{F1}$$

$$V_C = 16V_{F2} + 4V_{F1} + V_{P1} + V_{P2}$$

The sampling errors are the square roots of the variances and significant differences of the values A, B, and C from 0 is tested by a Student's t-test (with degrees of freedom as the sum of (n - 1) for the generations involved).

Weighted least squares were used to estimate genetic parameters in the three parameter joint scaling tests. The parameters m, a, and d were computed through matrix algebra according to the method of Rowe and Alexander (1980); where m represents the mean value, a represents the additive effect, and d represents the dominance effect. The statistical procedure was described as follows:

1) Define the following matrices

$$N = \begin{bmatrix} n(P1) & & & & & \\ & n(P2) & & & & \\ & & n(F1) & & & \\ & & & n(F2) & & \\ & & & & n(B1) & \\ & & & & & n(B2) \end{bmatrix} \qquad S = \begin{bmatrix} s^2(P1) & & & & & \\ & s^2(P2) & & & & \\ & & s^2(F1) & & & \\ & & & s^2(F2) & & \\ & & & & s^2(B1) & \\ & & & & & s^2(B2) \end{bmatrix}$$

$$Y = \begin{bmatrix} \overline{P1} \\ \overline{P2} \\ \overline{F1} \\ \overline{F2} \\ \overline{B1} \\ \overline{B2} \end{bmatrix} \qquad C = \begin{bmatrix} 1 & 1 & 0 \\ 1 & -1 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 0.5 \\ 1 & 0.5 & 0.5 \\ 1 & -0.5 & 0.5 \end{bmatrix} \qquad M = \begin{bmatrix} m \\ a \\ d \end{bmatrix}$$

The diagonal elements of matrix N consists of the number of ears measured for pericarp thickness in a particular generation. The diagonal elements of matrix S are the sample variances corresponding to the values of matrix N. Y is the vector of the generation means. Matrix C is the genetic expectations of the six generations in terms of the three parameters of the additive-dominance model. M is the vector of the genetic parameters which will be estimated by the method of least squares.

2) The parameter estimates m, a, and d are obtained by the following equation:

$$M = (C'NS^{-1}C)^{-1} C'NS^{-1}Y$$

where ' indicates the transpose and $^{-1}$ the inversion.

3) The expected generation means are derived by:

$$\hat{Y} = CM$$

4) The chi^2 value to assess whether or not the data fits the additive-dominance model is obtained by:

$$chi^2_{(k - p)} = (Y - \hat{Y})'(NS^{-1})(Y - \hat{Y})$$

where k is the number of generation means and p is the number of parameters estimated.

5) The variances of the parameter estimates are the products of the diagonal elements of $(C'NS^{-1}C)^{-1}$ and $chi^2 \div (k - p)$. These variances were used to obtain the standard errors of the estimates, and the Student's t-test to determine whether or not the parameters were significantly different from 0 (with k - p degrees of freedom).

The six-parameter model, which is an extended model containing digenic epistasis can be fitted by assuming that higher orders of epistasis is absent. The means of the six generations (P1, P2, F1, F2, B1, and B2) were used to estimate the six parameters by the formulas outlined by Gamble (1962):

$$m = \overline{F2}$$

$$a = \overline{B1} + \overline{B2}$$

$$d = -\tfrac{1}{2}\overline{P1} - \tfrac{1}{2}\overline{P2} + \overline{F1} - 4\overline{F2} + 2\overline{B1} + 2\overline{B2}$$

$$aa = - 4\overline{F2} + 2\overline{B1} + 2\overline{B2}$$

$$ad = -\tfrac{1}{2}\overline{P1} + \tfrac{1}{2}\overline{P2} + \overline{B1} + \overline{B2}$$

$$dd = \overline{P1} + \overline{P2} + 2\overline{F1} + 4\overline{F2} - 4\overline{B1} - 4\overline{B2}$$

The three added parameters detect three types of epistasis: 1) aa

represents additive x additive interactions; 2) ad represents additive x dominance interactions; and 3) dd represents dominance x dominance interactions.

The variances of the parameters were derived by the variances of the generation means involved in the calculation of each parameter. For example, the variance of d is:

$$V_d = \tfrac{1}{4}V_{P1} + \tfrac{1}{4}V_{P2} + V_{F1} - 16V_{F2} + 4V_{B1} + 4V_{B2}$$

$$s_d = (V_d)^{\frac{1}{2}}$$

The significance of the parameters can be tested by the Student's t-test. For example, the significance of d can be tested by:

$$t = d/s_d$$

The number of degrees of freecom is the sum of (n - 1) of the generations involved in estimating the parameters.

The generation mean analysis involved crosses between sweet and field corn inbred lines. Therefore, segregation of + (normal) and su (sugary) types of endosperm would appear on the P1, F1, F2, and B2 ears. It was suspected that the underlying endosperm would affect pericarp thickness since the su type of kernels are wrinkled, whereas the + type of kernels are smooth and round at maturity. Thus, it seems that + kernels may have pericarps that are stretched out to a greater extent than the su kernels. This hypothesis was tested by removing both + and su types of kernels from the F1 ears only and evaluating them for pericarp thickness.

1.3.4 Evaluation of Sweet Corn Hybrids for Pericarp Thickness at Two Locations

Twelve major sweet corn hybrids grown commercially in the U.S. were

evaluated for pericarp thickness. The hybrids evaluated were: Jubilee, Stylepak, Bonanza, H68, Nk51036, Iobelle, GCB (N), GCB (T), Midway, Silver Queen and Sweet Sue. The two locations of Lalamilo on the Island of Hawaii and Waimanalo on the Island of Oahu were selected because of their differences in temperature. Lalamilo is at a high elevation (2800ft) and is much cooler than at Waimanalo which is at sea level. The planting at Lalamilo took place during the winter months with temperatures about 65F while the plantings at Waimanalo took place during the summer months when temperatures were about 78F. It was hypothesized that temperature differences between these two locations would have different effects on pericarp thickness.

The experiment was set up as a randomized complete block design with two replications. Initially, the experiments were set up to observe the differences between locations and maturity by measuring pericarp thickness in 5 ears at sweet corn stage (20 days after pollination) and 5 ears at maturity. Four positions on the pericarp were to be measured. Positions 1 and 2 were the top and bottom of the germinal side of the pericarp and positions 3 and 4 were the bottom and top of the abgerminal side of the pericarp respectively. However, this experiment ran into a series of misfortunes. The ears at sweet corn stage were lost in the 1977 plantings at Lalamilo, whereas at Waimanalo, the ears in the mature stage were lost. Thus 5 ears of each hybrid were harvested at Waimanalo at sweet corn stage and 5 ears were harvested at Lalamilo at maturity. The ears at Lalamilo were analyzed by measuring four positions on the pericarp. But the ears at Waimanalo were measured at two positions (germinal and abgerminal), by the method described in

Section 1.3.1, since the pericarps were too small for the plunger of the micrometer to adequately measure 4 positions. The experiment was repeated in 1979 and again misfortune struck. A storm washed away the Lalamilo planting. This time it was decided that two positions be measured since there was no hybrid by position interaction in the analysis of the four positions in the previous experiment. Since the Waimanalo planting came in before the Lalamilo planting was washed away, four positions were not measured to give comparable results to that of the previous experiment. However, it was assumed that the average of positions 1, 2 and 3, 4 would be approximately equal to measuring the center of the germinal and abgerminal side of the kernels. Therefore, the Lalamilo planting of 1977 and the Waimanalo planting of 1979 were analyzed as a combined analysis of variance to observe the interactions between locations, hybrids, and positions on the pericarp. Similarly, the sweet corn data of the 1977 Waimanalo planting and the mature ear data of the 1979 Waimanalo planting were analyzed as a combined analysis of variance to observe the interactions between maturities, hybrids, and positions on the pericarp.

1.3.5 Pericarp thickness of Some of the Races of Maize

Ninety five races of maize were evaluated for pericarp thickness. These were not necessarily all different races as multiple samples were taken within some of the races since they were different in kernel characteristics or because they were from different seed stocks. Bulked samples were obtained from the seedstocks maintained by Dr. J. L. Brewbaker at the University of Hawaii and analyzed for pericarp thickness by the method described in Section 1.3.1.

1.3.6 Pericarp Thickness of Various Endosperm Mutant Lines

Two experiments were conducted to inquire about the effects of the underlying endosperm on pericarp thickness. Fifteen mutants converted to the CM104 background were analyzed for pericarp thickness. CM104 (normal) was used as a control. The mutants analyzed were: bt, bt2, du, fl, fl2, h, o, o2, o2b, sh, sh2, sh4, su, su2, and wx. The other experiment was the evaluation of pericarp thickness of various inbred lines and their o2 conversions. The inbreds evaluated were: Ant2, B37, B68, CM105, CM111, Hi30, Mo17, Oh43; and their o2 counterparts. For each of these experiments, twenty samples of mature seeds were bulked from the seedstocks maintained by Dr. J. L. Brewbaker and evaluated for pericarp thickness by the method described in Section 1.3.1.

1.4 RESULTS AND DISCUSSION

1.4.1 Cyclical Mass Selection for Tenderness

Cyclical mass selection for tenderness was conducted on 'Hawaiian Super-sweet No. 9' on a 10% selection intensity using criteria of pericarp thickness measurements and bite-test scores on a hedonic scale of 5. For the first cycle of selection only, the effects of maturity differences of the unpollinated ear on pericarp thickness was evaluated. The product-moment correlation coefficient between bite-test scores and their respective pericarp thicknesses was also derived. The final evaluation of all selection cycles for tenderness assessed the results of the pericarp thickness criterion on the bite-test criterion and vice versa.

1.4.1.1 Correlation of Pericarp Thickness With Bite-test and Maturity Tests of the Unpollinated Ear

The mean pericarp thicknesses for each of the 5 bite-test scores are presented in Table 1. Comparisons of the average pericarp thicknesses with each of the 5 bite-test scores indicate that there was a trend of increasing pericarp thicknesses with increasing bite-test scores. The product-moment correlation coefficient for the overall pericarp thickness means and the bite-test scores was highly significant ($r = 0.98$). However, when using the means of the 5 kernels from each of the 376 individual ears to determine the correlation, the correlation coefficient was small ($r = 0.24$) but highly significant, due partially to the large sample size. Its coefficient of determination was small ($r^2 = 0.056$) suggesting that a small portion of the sum of squares of

Table 1

Mean pericarp thickness in microns for each bite-test score and relative maturity rating

Bite-test Score	Pericarp Thickness At Relative Maturity And Bite-test Score[a]											
	Early			Medium			Late			Average		
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s
1	0	-	-	3	42.3	3.5	4	42.4	7.0	7	42.6a	7.0
2	20	42.5	6.8	41	44.3	6.9	12	45.3	6.9	73	44.8ab	6.8
3	30	46.8	8.0	75	44.6	6.5	58	46.8	8.0	163	45.7b	7.4
4	18	49.8	6.2	55	47.4	7.0	41	45.6	10.6	114	48.5c	8.4
5	3	48.8	6.6	10	50.6	9.6	6	55.1	9.8	19	51.7d	9.0
Average	71	47.3	7.2	184	45.8	7.1	121	47.8	9.2	376	46.6	7.9

[a] Relative maturity is defined as silk length, n = number of samples, $\bar{x}$ = mean, s = standard deviation, and mean separation in Average column by Duncan's multiple range test, 5% level.

Table 2

Analysis of variance for maturity (defined as silk length) and for pericarp thickness data in Table 1

Source	df	Mean Square
Treatment	(14)	129.6***
Pericarp Thickness (PT)	4	357.8***
Maturity (M)	2	188.1*
PT X M	8	0.9
Error	361	59.4

the pericarp thickness of the individual ears was attributable to the bite-test scores and vice versa. The correlation between pericarp thickness and bite-test scores is evident in the bivariate and frequency distribution plot (Figure 1). Most of the pericarp thickness values are concentrated around the regression line, however, there were a few ears with low pericarp thicknesses associated with high bite-test scores and vice versa. The scatter reflects the large standard deviation associated with the pericarp thickness means for the bite-test scores (Table 1). This suggests that bite-testing as carried out was not precise as is desired or that pericarp thickness was not the only factor determining tenderness as quantified by bite-testing.

Highly significant differences were observed between pericarp thickness measurements associated with each of the 5 bite-test scores (Table 2). Mean separation of pericarp thickness measurements by the Duncan's multiple range test for each of the 5 bite-test scores (Table 1) showed that differences were not significant between the 1 and 2 bite-test scores and the 2 and 3 scores. On the other hand, significant differences occurred among the 3, 4, and 5 bite-test scores, suggesting that tenderness may not be readily distinguished as toughness is.

The 95% confidence intervals for mean pericarp thicknesses of the 5 bite-test scores are presented in Figure 2. The confidence intervals are wider at the bite-test scores of 1 and 5 due largely to the small sample size obtained for these scores and to the variations in pericarp thickness at these scores (Figure 1). At bite-test scores of 2, 3, and 4, the confidence intervals are quite narrow indicating that the bite-test can accurately predict a specific pericarp thickness in 'Hawaiian Super-sweet No. 9'. It is probable that increasing sample

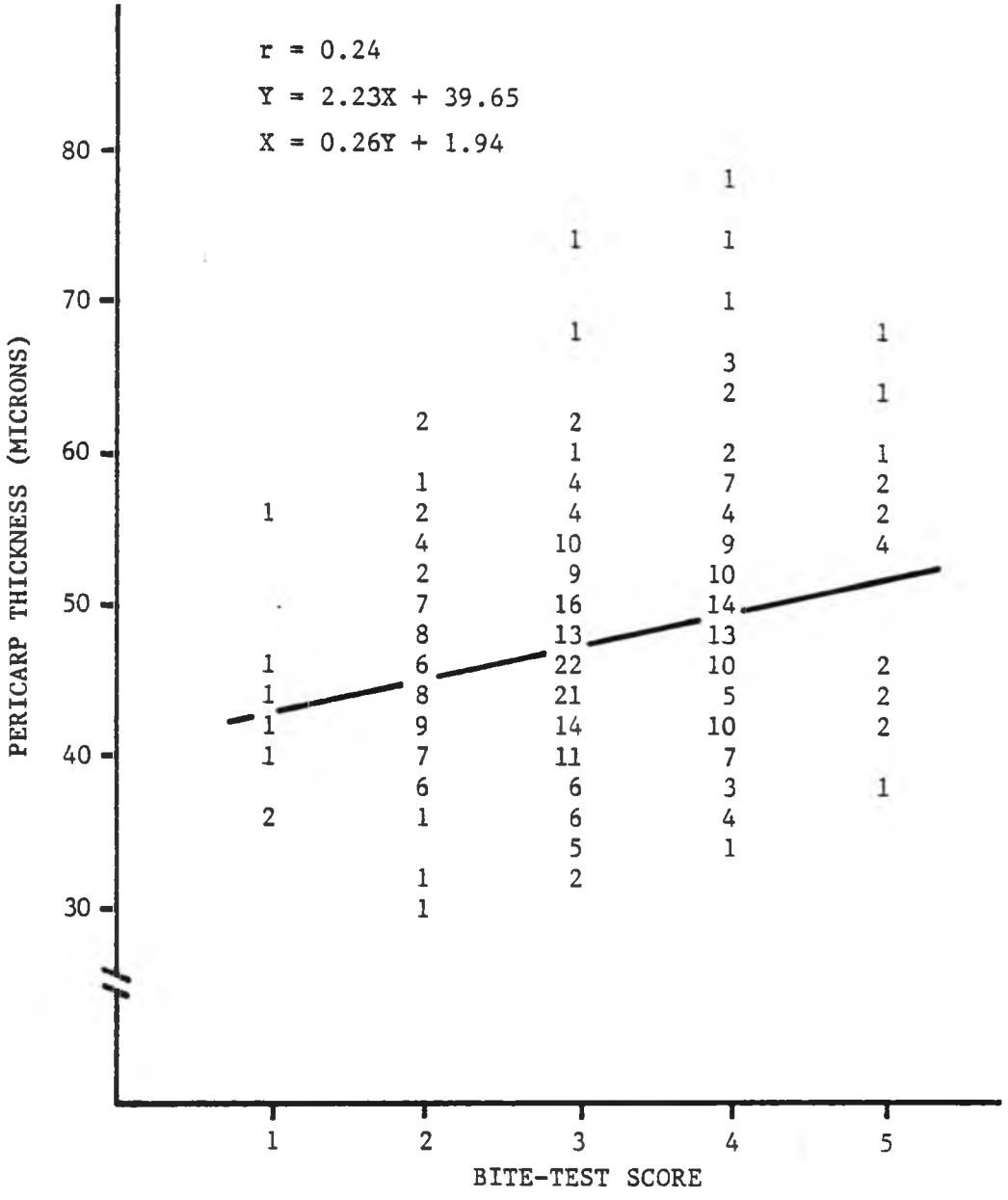

Figure 1. Bivariate scatter and frequency-plot of pericarp thickness on each respective bite-test score

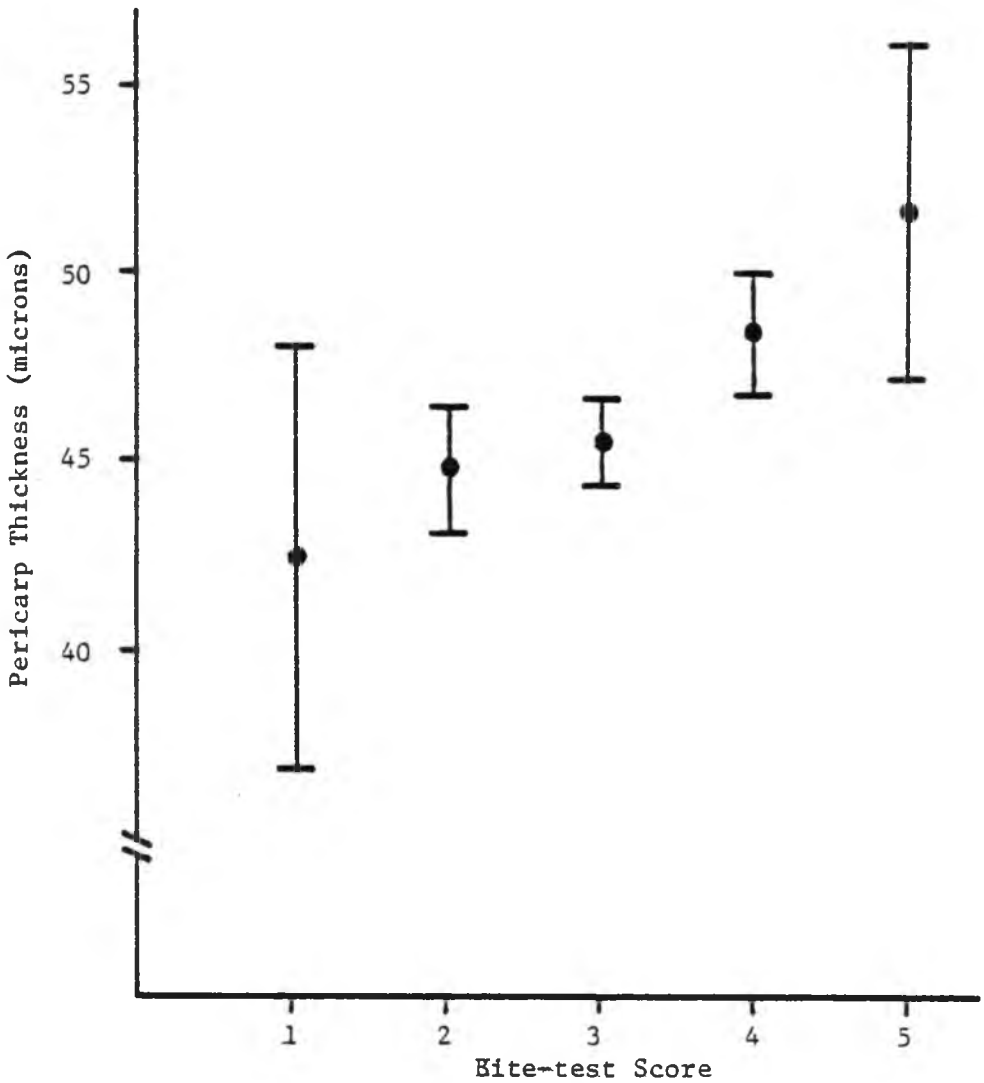

Figure 2. Confidence intervals (95%) around the mean pericarp measurements for each bite-test score

sizes at the 1 and 5 bite-test scores would decrease the width of the confidence intervals. It is also likely that the correlation and regression between pericarp thickness and bite-test values would also improve upon increasing the sample sizes at these bite-test scores.

The frequency distribution of the bite-test was expected to be normal considering that no known selection pressure on pericarp thickness existed in the base population. However, the distribution was slightly skewed towards higher bite-test scores (Table 1). This can be attributed to the fact that bite-testing was conducted slightly past prime sweet corn stage, biasing the scores upwards.

There was no definite trend observed in the pericarp thicknesses among the early, medium, and late maturity ratings for the earshoots prior to pollination (Table 1). Significant differences among these values were observed at the 5% level only (Table 2). This indicates that pericarp development is initiated only after pollination occurs and that two to three days developmental differences between the unpollinated ears do not affect the development of the pericarp.

1.4.1.2 Selection for Pericarp Thickness and for Lower Bite-test Scores

All of the cycles of selection by pericarp thickness and by bite-test were assessed by pericarp thickness measurements. The mean pericarp thickness and dispersion statistics around the mean values for the germinal, abgerminal, and the average of the germinal and abgerminal positions are presented for each cycle of selection in Table 3. C0 refers to the initial population, P1, P2, P3, refers to

the pericarp thickness selection, and B1, B2, B3, B4 refers to selection by bite-testing. Significant reductions in pericarp thickness was obtained following selection based on pericarp thickness, while marginal reductions were observed for selection through bite-testing. These reductions were quite similar in both the germinal and abgerminal positions. Mean separation of the average means by the Duncan's BLSD shows that there was a nonsignificant reduction of pericarp thickness for selection cycle P1, however substantial progress towards reducing pericarp thickness occurred for cycles P2 and P3. This probably occurred as pericarp thickness for P1 was measured at a stage slightly past prime sweet corn stage (about 22 days after pollination), while pericarp thickness was taken at maturity for P2 and P3. A linear decrease in pericarp thickness (approximately 8 microns) was observed for P2 and P3. These changes are clearly represented in Figure 3.

In the cycles of selection utilizing the bite-test, the Duncan's BLSD indicates that there were insignificant changes in pericarp thickness from C0 to selection cycle B2. The slightly higher thickness of B2 was possibly due to the ill weather conditions at the time of silking. There was considerable lodging and many shootbags were blown away resulting in limited sample size and control of maturity over the ears. After B2, a significant decrease in pericarp thickness from C0 was observed. The decrease in pericarp thickness for B3 and B4 were similar to the decrease in pericarp thickness for B1. The magnitude of decrease was about 3 microns and this is clearly illustrated in Figure 3.

Based on the standard deviations and the standard errors of the mean, substantial decreases in the variances were observed in the

Table 3

Statistics of dispersion for mean pericarp thickness in microns from selection by pericarp thickness and by bite-test

Position	Cycles	$\bar{x}$	s	$s_{\bar{x}}$	C.V.	n[b]
	C0	68.5	13.47	0.71	19.66	370
	P1	64.4	13.56	0.63	21.05	466
	P2	56.9	10.90	0.51	19.14	452
Germinal	P3	49.0	10.76	0.50	21.97	461
	B1	65.5	13.43	0.51	20.49	460
	B2	66.4	13.39	0.66	20.18	400
	B3	63.3	13.83	0.83	21.84	265
	B4	61.0	12.29	0.58	20.16	454
	C0	78.8	15.08	0.78	19.13	370
	P1	75.3	17.97	0.81	23.86	466
	P2	66.7	14.20	0.68	21.28	452
Abgerminal	P3	57.6	13.38	0.60	23.24	461
	B1	76.3	15.44	0.77	20.22	460
	B2	78.1	15.51	0.73	19.87	400
	B3	74.6	16.17	0.95	20.56	265
	B4	71.5	14.62	0.70	20.44	454
	C0	73.7a[a]	15.24	0.56	20.62	740
	P1	69.9a	16.82	0.54	24.07	932
	P2	61.8b	13.56	0.46	21.93	904
Average	P3	53.3c	12.87	0.42	24.17	922
	B1	70.9ab	15.44	0.51	21.76	920
	B2	72.2ab	15.62	0.55	21.63	800
	B3	69.0bc	16.07	0.68	23.29	530
	B4	66.2c	14.50	0.49	22.34	908

[a] Mean separation by Duncan's BLSD, 5% level (BLSD = 4.23). Pericarp thickness and bite-test selection observed separately.

[b] n represents the number of data entering the mean. n in the Average row divided by 10 represents a close approximation of the number of ears in each selection cycle.

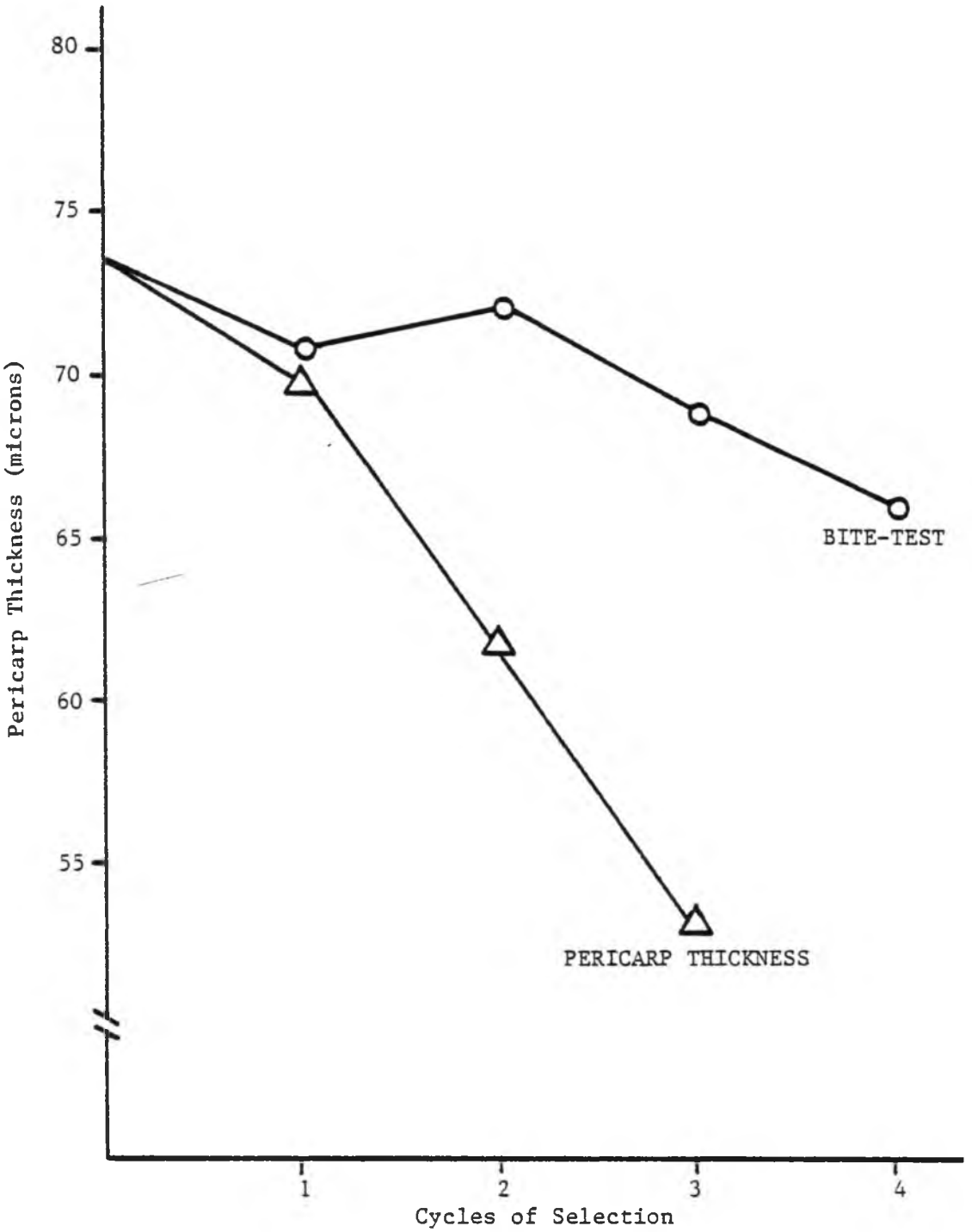

Figure 3. Mean pericarp thickness for cycles of selection selected through criteria of pericarp thickness and bite-test

cycles of selection based on pericarp thickness (Table 3). Similar decreases in pericarp thickness were observed for the germinal, abgerminal, and the average of both positions. However, no important decreases in the variances were seen in the cycles of selection bases on bite-testing. This was expected since bite-testing was not precise in predicting pericarp thickness (Section 1.4.1.1).

The total number of ears measured in each cycle may be estimated by dividing the sample size in the average row (which was the number of pericarps measured at two positions) by 10 (the number of data taken per ear. The lower number of ears in B3 resulted from the fact that the ears were not covered tightly by the husks after bite-testing, hence the kernels dried prematurely and were damaged by insects resulting in poor germination. For future experiments, the husks should be carefully removed down to the base of the ears, preferably without much shredding. This would facilitate tight covering of the ears after bite-testing.

The mean squares for cycles were highly significant for variance analyses for the germinal position (Table 4), abgerminal position (Table 5), and in the combined analysis of variance for both positions (Table 6). In all analyses (Tables 4, 5, and 6), the sampling errors, which were based on differences between ears within plots, were highly significant when contrasted to the intra-ear or between-kernel variance component (which was derived from measurements on one position, normally on 5 kernels per ear). This added variance component was due to genetic and/or environmental effects on the pericarp thicknesses between ears. All of the experimental errors (Tables 4, 5, and 6) were

Table 4

Analysis of variance for pericarp thickness in microns for the germinal position in Table 3

Source	df	Mean Square
Replication	9	2235.1***
Cycles	7	17446.0***
Experimental Error	63	643.4
Sampling Error	631	534.4***
Subsampling Error	2617	51.4

Table 5

Analysis of variance for pericarp thickness in microns for the abgerminal position in Table 3

Source	df	Mean Square
Replication	9	3502.2***
Cycles	7	22390.8***
Experimental Error	63	1370.4
Sampling Error	631	716.9***
Subsampling Error	2617	79.24

Table 6

Combined analysis of variance (germinal and abgerminal positions) for pericarp thickness in microns in Table 3

Source	df	Mean Square
Position	1	181312.0***
Replication	9	5496.9***
Error a	9	240.0
Cycles	7	39638.8***
Cycles X Positions	7	196.6
Error b	126	1006.9
Sampling Error (between ears)	1262	625.6***
Subsampling Error (within ears)	5234	63.5

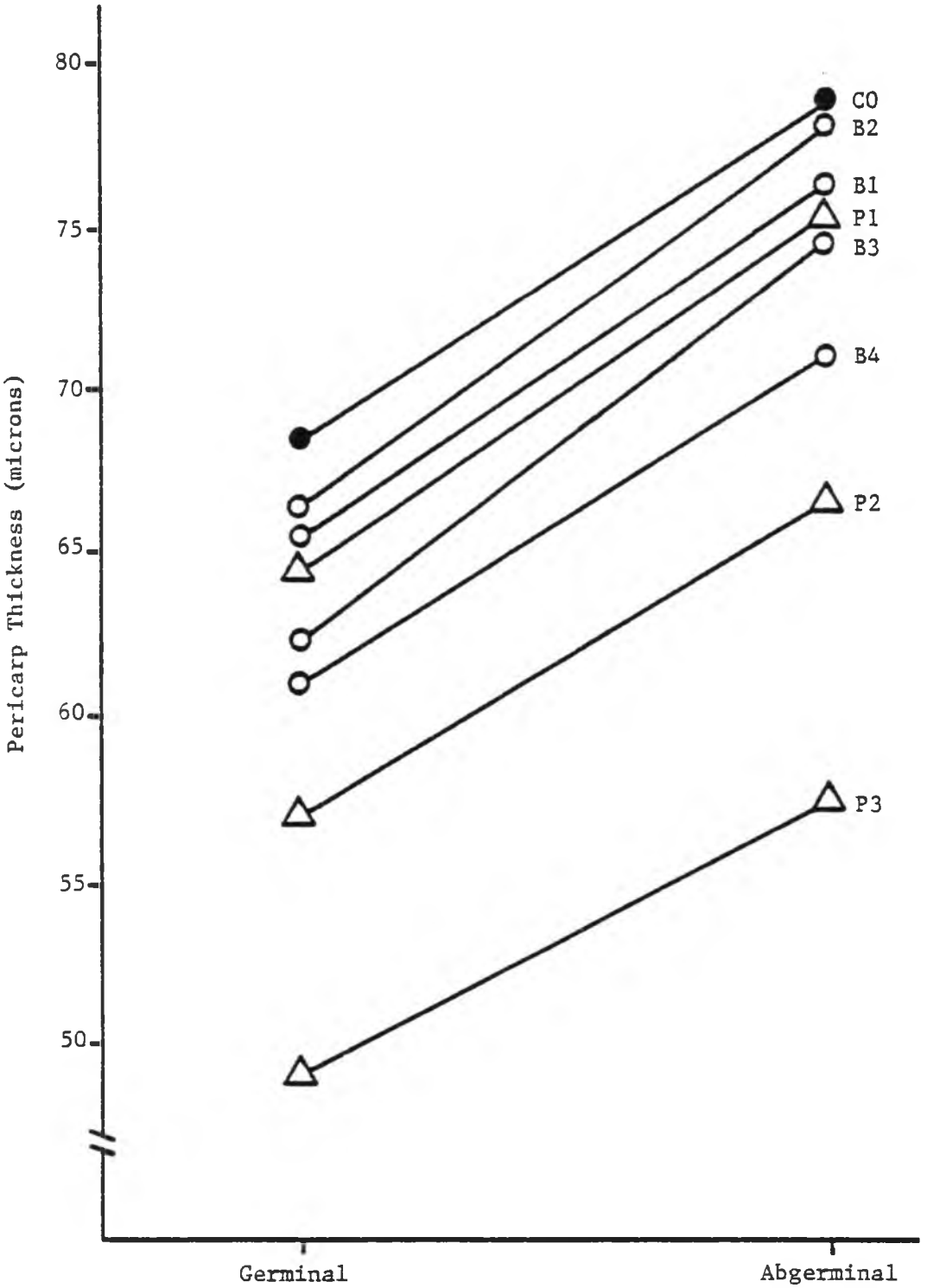

Figure 4. Mean pericarp thickness of the germinal and abgerminal positions for each cycle of selection by criteria of bite-test or by pericarp thickness

not significant indicating that all plots within the same cycle behaved similarly. All of the replication mean squares were significant suggesting that pericarp thickness was affected by the environment. This environmental effect on the pericarps was observed to be random among the replications (Appendix--Table 38). The combined analysis of variance included a very large mean square for positions in contrast to the minute interaction mean square for cycles by position. There is no doubt that, in 'Hawaiian Super-sweet No. 9', highly significant differences existed between the germinal and abgerminal positions regardless of selection pressures for tenderness, and that these differences were consistent for each selection cycle. This consistency in the differences between the two positions is clearly represented in Figure 4. The parallel behavior of the lines indicates that there was no interaction between cycles and positions.

Bite-test evaluations were also conducted on the cycles of selection for tenderness by criteria of pericarp thickness and by bite-test, with data from about 100 ears per cycle. In contrast to the pericarp thickness evaluation, the bite-test selection showed more rapidly decreasing scores than the pericarp thickness selection (Figure 5). A definite downward trend occurred for both criteria of selection, however most of these changes were statistically insignificant due to the large standard deviations associated with each of the bite-test scores. This, again, indicates the imprecise nature of the bite-test which is expected of subjective methods of evaluations. The mean and dispersion statistics about the mean bite-test scores are presented in Table 7. The Duncan's BLSD shows that the decrease in the bite-test

Table 7

Statistics of dispersion for bite-test scores from selection by pericarp thickness and by bite-test

Cycles	$\bar{x}$[a]	s	$s_{\bar{x}}$	C.V.	n[b]
C0	2.98a	0.68	0.08	27.7	96
P1	2.97a	0.48	0.07	23.3	93
P2	2.87a	0.54	0.07	25.5	102
P3	2.72a	0.49	0.07	26.3	90
B1	2.78ab	0.53	0.07	26.1	100
B2	2.56b	0.55	0.07	28.5	96
B3	2.50b	0.65	0.09	32.0	85
B4	2.51b	0.66	0.08	32.4	91

[a] Mean separation by Duncan's BLSD, 5% level (BLSD = 0.37). Bite-test and pericarp thickness selection observed separately.

[b] n represents the number of ears that were bite-tested.

Table 8

Analysis of variance for bite-test scores in Table 7

Source	df	Mean Square
Replication	9	1.35
Cycles	7	3.62*
Experimental Error	63	1.32*
Sampling Error	673	0.45

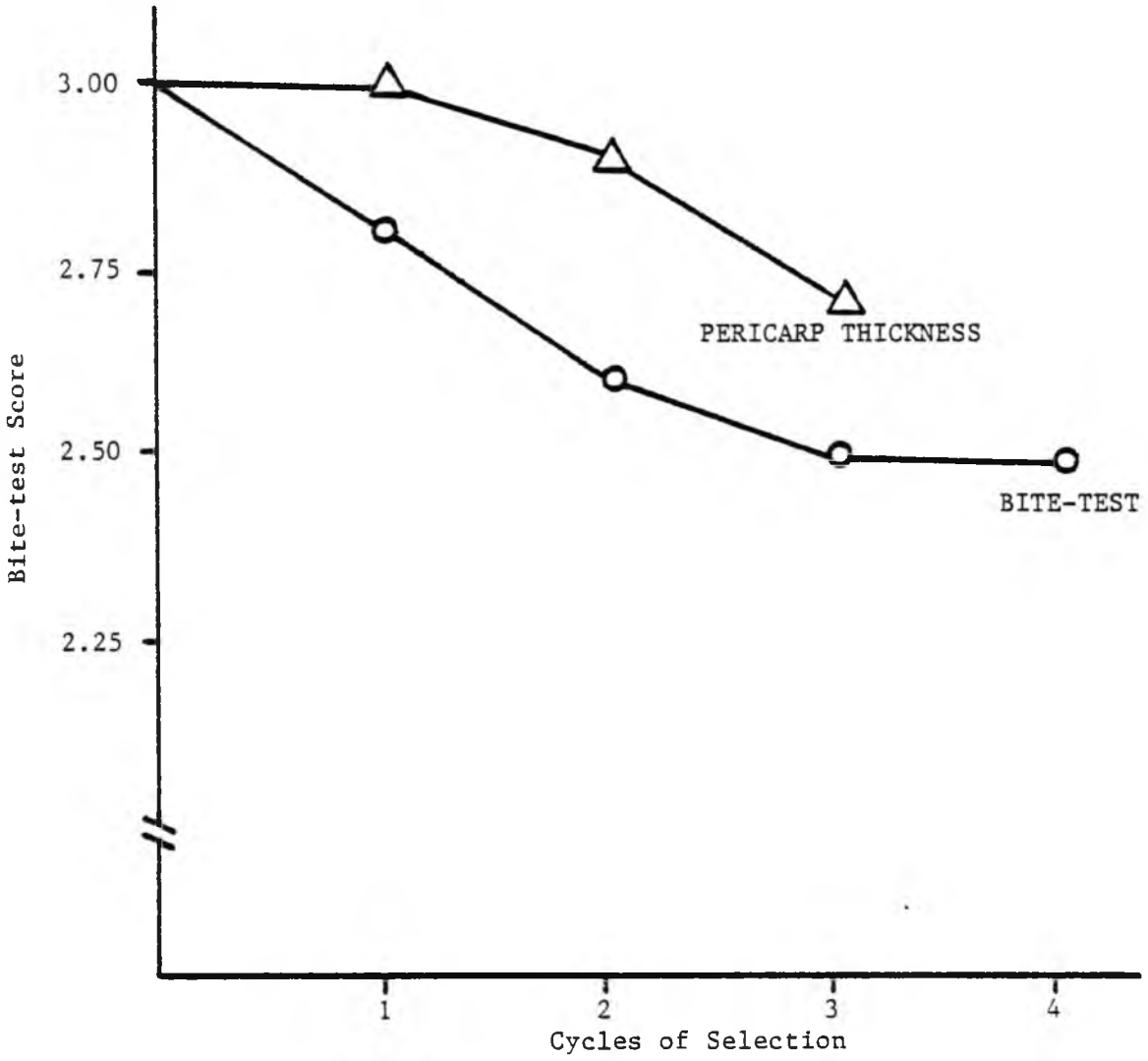

Figure 5. Mean bite-test scores for cycles selected for by criteria of pericarp thickness and bite-test

scores for P1, P2, and P3 were not significant. B1 was not significantly different from C0, however, significant differences from C0 were observed for B2, B3 and B4.

The mean square for cycles of selection is significant at the 5% level (Table 8), mostly due to the reduction in bite-test scores for B2, B3, and B4. The experimental error is also significant at the 5% level. This significance was due to random differences among the replications regardless of the fact that the bite-test was conducted on two separate days with a one day interval in between (Appendix—Table 39).

1.4.1.3 Discussion

Reduction of pericarp thickness is of primary concern to the sweet corn breeder because of its pronounced effect on tenderness when other factors, primarily maturity, are constant (ref. Section 1.2.2). A rapid and accurate method of selecting for pericarp thickness would be valuable in producing sweet corn varieties and hybrids. Evaluations of pericarp thickness by micrometry and by bite-testing are two methods of assessing tenderness; the former being quantitative and precise, but time consuming, and the latter being subjective and less precise, but rapid and accurate in determining tenderness. When conducting a bite-test, there is little difficulty in distinguishing between the 1, 2 and 4, 5 bite-test scores. Considering that a high correlation was found between pericarp thickness measurements and bite-test scores, it can be concluded that either method accurately predicts tenderness. However, the large standard deviation coupled with the large scatter of pericarp thickness measurements around the bite-test scores indicates that the bite-tester may shift his judgement relative to the ears most recently tested.

The lack of significant progress in the bite-test evaluations of the pericarp thickness selection may be due to testing at a stage later (23 days after pollination) than at prime sweet corn stage (19-20 days after pollination). At late sweet corn stage, the endosperm probably had a greater effect on tenderness than pericarp thickness.

Greater progress in the bite-test selection when evaluated by bite-testing, could have been due to factors other than pericarp thickness. Culpepper and Magoon (1924) reported that the differences in endosperm compaction between ears is important in determining tenderness. The bite-test would be adversely affected by developmental differences of the endosperm between ears when correlated to pericarp thickness. Ears of a variety such as 'Hawaiian Super-sweet No. 9' could possibly have genetic differences in the rate of endosperm development. This factor along with environmental influences could partially nullify efforts to ensure uniform maturity by allowing simultaneous pollination of the ears. Thus, ears that produce dry matter in the endosperm at a slower rate may have been indirectly selected for, consequently, lower bite-test scores would be obtained despite the pericarp thickness. If this is the case, comparable results between pericarp thickness selection and bite-test selection would be more difficult to obtain than expected. Unfortunately dry matter was not measured in this experiment. For future experiments, measurements on dry matter content as a measure of maturity would be a useful covariate to observe whether or not there are developmental differences between the ears and if it exists, its effect on tenderness.

The nonsignificant interaction of cycle by position suggests that

measurements of either one position are accurate enough to permit significant progress in selection for pericarp thickness. Selection of the germinal position seems most logical since there appears to be less variability to contend with according to the standard deviation, standard error of the mean and the coefficient of variation. However, the differences of the dispersion statistics between the germinal and abgerminal positions are not large.

Quantitative genetic studies by Ho et al. (1975) and by Helm and Zuber (1972a) indicated that a large proportion of the phenotypic variance was additive genetic variance. Narrow sense heritability estimates derived by Ho et al. (1975) and by Helm and Zuber (1972a) was 72% and 80% respectively. This indicated that large gains can be made in selection for pericarp thickness. In this experiment, fairly large decreases in pericarp thickness were obtained by selecting for thin pericarps. Further progress in selection for pericarp thickness is deemed likely. Generally, selection for any highly heritable character results in rapid progress in the initial cycle, a lag phase, and finally a plateau (Allard, 1960). A linear decrease of about 8 microns in pericarp thickness occurred from P1 to P3 with no evidence of a lag phase. It was also observed that some ears averaged pericarp thickness down to 25-30 microns, and selection down to this level is possible. However, selection of a desirable thickness will depend on factors other than tenderness. Kernels with thin pericarps have a tendency to damage easily which adversely affects germination (Banafunzi, 1974; Tatum, 1942; and Meyers, 1924), and the ability to withstand diseases (Koehler, 1957; and Alberts, 1927). It was observed in the field that a few ears produced extremely thin pericarps which resulted in splitting at the crown of the kernels. The

frequency of this undesirable effect may be increased with advanced cycles of selection for thinner pericarps.

1.4.2 Genetic Study of Pericarp Thickness

1.4.2.1 Generation Mean Analysis

A quantitative genetic study was developed from crosses involving two parents with thin pericarps and four parents with thick pericarps. The thin pericarped parents were AA8 (54.6 microns) and 677a (50.5 microns); and the thick pericarped parents were CI21E (98.5 microns), B68 (132.3 microns), B37 (107.7 microns), and H55 (82.0 microns). Six of the eight possible crosses were analyzed. The generation means (P1, P2, F1, F2, B1, and B2) of these crosses are summarized in Table 9. The F1 means of all crosses were consistently closer to the mean of the thin pericarped parent, exhibiting partial dominance for thin pericarps. The means of the F2 were less than the F1 means in all cases except for AA8 X B68 and AA8 X H55. It is possible that this was due to duplicate genes with cumulative effects. The backcross means consistently show a reversion towards the means of the recurrent parent with the exception of the crosses involving H55. The data suggests that H55 may have more genes for thin pericarps than for thick pericarps.

The frequency distributions of the six generations in each of the six crosses are presented in Figure 6. Data were graphed to the nearest 10 microns for presentation. In every case, the distributions of the thin and thick parents are distinctly separated. Generally, the frequency distributions of the F2 in each cross is more often skewed towards the P1 distributions than that of the F1 distributions. The

Table 9

Mean pericarp thickness in microns of parents, F1, and advanced generations

Crosses	P1	P2	F1	F2	B1	B2
AA8 X CI21E	54.6	98.5	68.9	58.9	51.2	73.3
AA8 X B68	54.6	132.3	68.6	74.4	63.5	78.8
AA8 X H55	54.6	82.0	51.3	59.9	57.5	54.2
677a X B68	50.5	132.3	81.1	61.3	52.2	103.2
677a X B37	50.5	107.7	77.1	62.1	63.5	102.6
677a X H55	50.5	82.0	61.4	52.1	49.6	61.1
Average	52.1	105.8	67.9	61.5	56.2	78.9

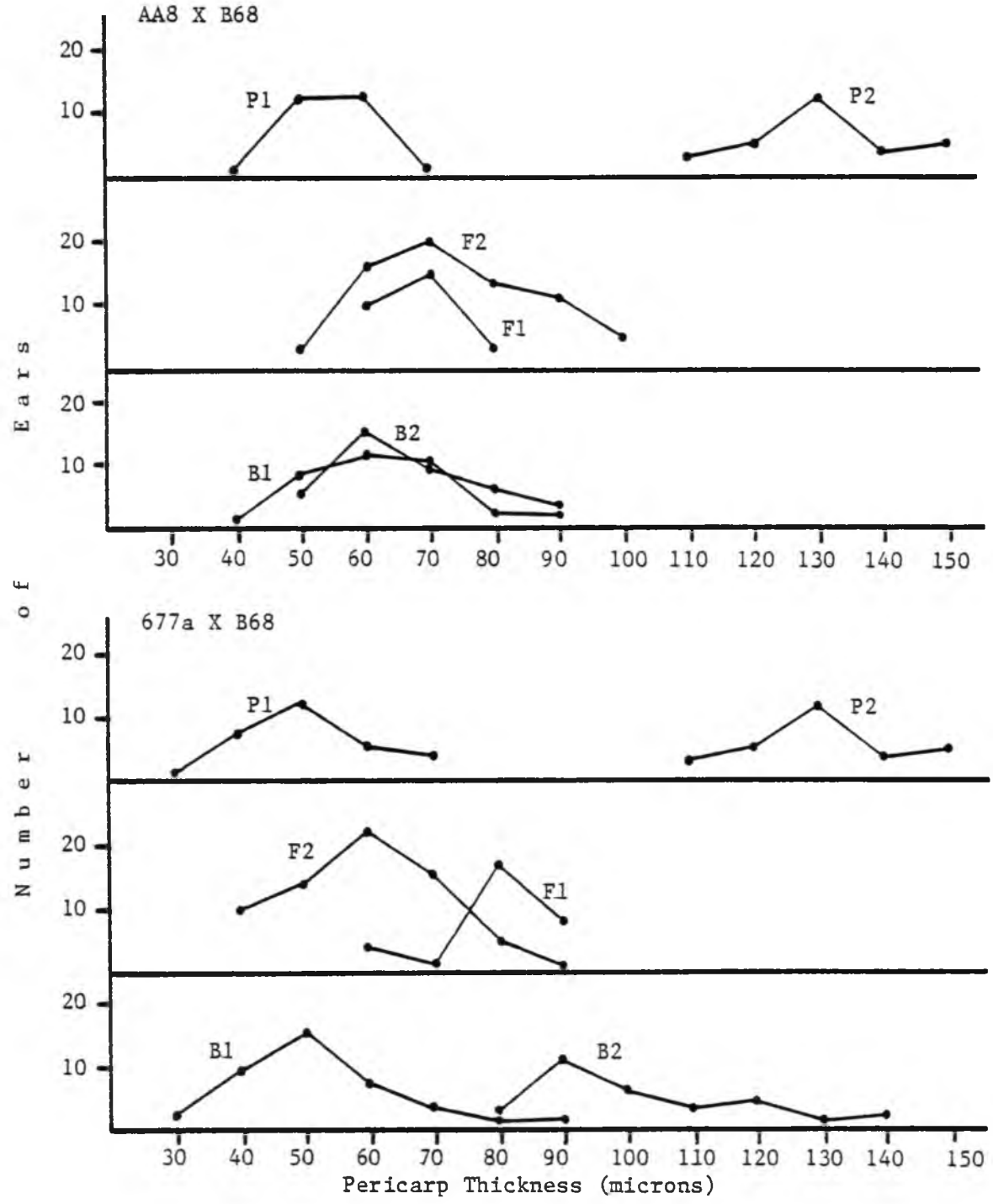

Figure 6. Frequency distribution of pericarp thickness in each genetic population

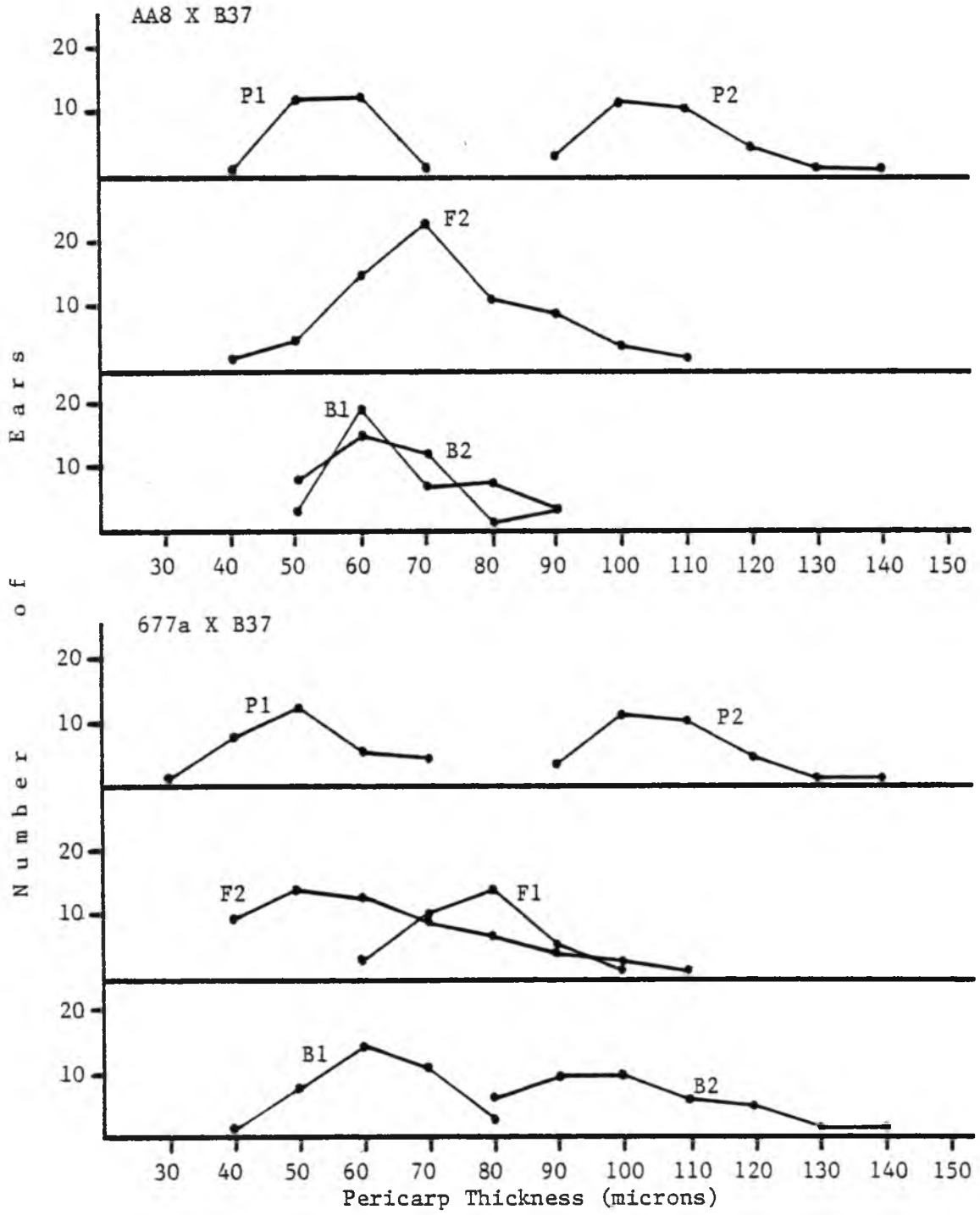

Figure 6. (continued) Frequency distribution of pericarp thickness in each genetic population

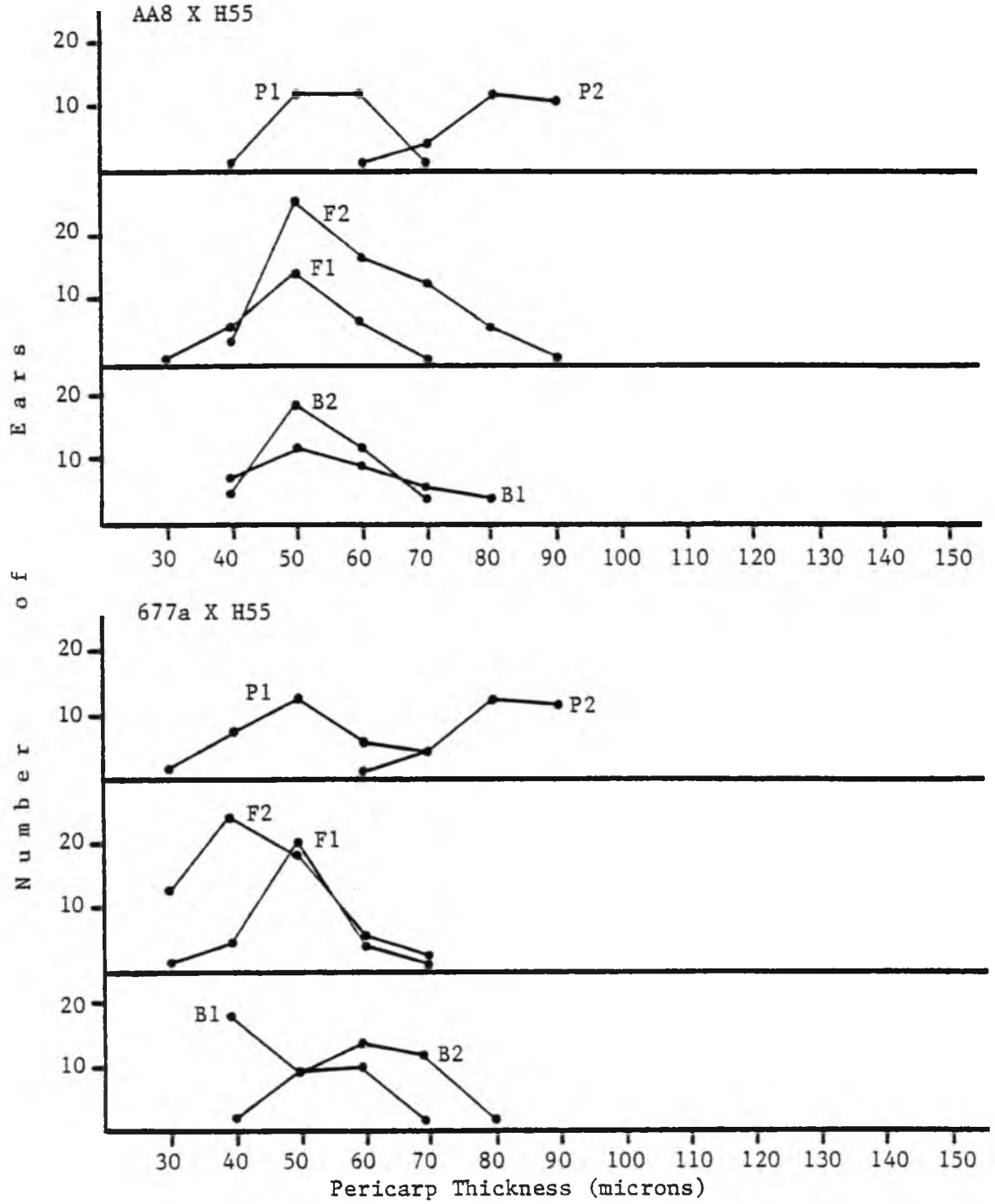

Figure 6. (continued) Frequency distribution of pericarp thickness in each genetic population

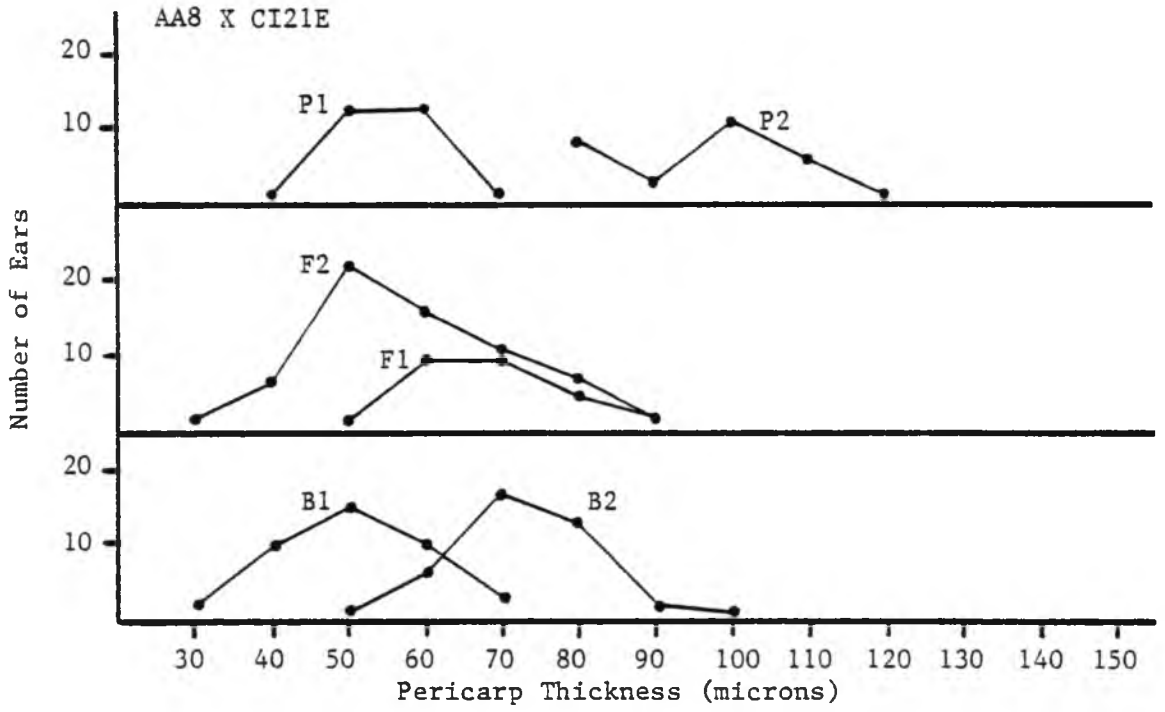

Figure 6. (continued) Frequency distribution of pericarp thickness in each genetic population

backcross distributions of the crosses with the AA8 parent overlap more than the crosses with 677a as a parent. The backcrosses involving 677a also segregated more towards the extreme parental values than crosses involving AA8. The B1 distributions which are skewed towards the P1 distributions suggest that continued backcrossing to a thin pericarped line can produce favorable results upon selection. Dominance for thin pericarps is indicated by the fact that the F2 and backcross distributions are oriented towards the parent with thin pericarps. All of the F2 distributions were situated well within the range of the distributions of the parents indicating no evidence of transgressive segregation.

The adequacy of the additive-dominance model was tested by the methods outlined by Mather and Jinks (1971) and by Rowe and Alexander (1980) for all of the crosses. If the model proves to be adequate, then gene effects may be attributed purely to intra-allelic additive and dominance effects. If deemed unsatisfactory, then factors other than allelic gene effects are affecting pericarp thickness.

The values for A, B, and C should be equal to 0 within the limits of the sampling error if the additive-dominance model is adequate. The values for A, B, and C did not differ significantly from 0 for all of the crosses (Table 10). This indicates that epistasis effects are not important in determining pericarp thickness. Since epistasis was absent, the three-parameter joint scaling test was conducted by the matrix methods outlined by Rowe and Alexander (1980). This test estimated the three parameters from the means of the six families in each cross by the method of weighted least squares. These parameter values were then used to estimate the expected generation means. Goodness of

Table 10

Values for the quantities A, B, and C in scaling tests for the additive-dominance model

Crosses	A[a]	S.E.[b]	B[c]	S.E.[d]	C[e]	S.E.[f]
AA8 X CI21E	-21.0	24.1	-20.7	24.2	-55.4	65.6
AA8 X B68	3.8	24.0	-43.3	29.1	-25.4	60.9
AA8 X H55	9.2	27.0	-24.9	19.0	0.2	54.5
677a X B68	-27.2	28.6	-7.1	36.0	-99.9	66.0
677a X B37	-0.6	26.0	20.4	33.0	-64.1	78.4
677a X H55	-12.6	21.6	-21.2	20.8	-46.9	46.2

[a] $A = 2\overline{B_1} - \overline{P_1} - \overline{F_1}$

[b] $S.E._A = (4VB_1 + VP_1 + VF_1)^{\frac{1}{2}}$

[c] $B = 2\overline{B_2} - \overline{P_2} - \overline{F_1}$

[d] $S.E._B = (4VB_2 + VP_2 + VF_1)^{\frac{1}{2}}$

[e] $C = 4\overline{F_2} - 2\overline{F_1} - \overline{P_1} - \overline{P_2}$

[f] $S.E._C = (16VF_2 + 4VF_1 + VP_1 + VP_2)^{\frac{1}{2}}$

fit of the model was then evaluated by a chi-square test. The three parameters estimated were the mean (m, the midparental value), an additive genetic component (a), and a dominant or nonadditive genetic component (d). These parameter estimates are presented in Table 11. Values for the three parameters were also derived from logarithmic (base 10) and square root transformation of the data. With the exception of 677a X B37, all of the values of m, a, and d are significantly different from 0 for all of the crosses. This indicates that both additive and dominance effects are responsible for controlling pericarp thickness. The values for the additive parameter are generally larger than the values for the dominance parameter indicating that additive gene effects are more important than dominance gene effects. The negative signs of the d parameter indicate dominance towards thin pericarps. The chi-square values for each cross was derived from the sum of the squared deviation of the observed and expected generation means multiplied by the weighting factor ($1/s_{\bar{x}}^2$). Expected values assume complete additive and dominance effects. The chi-suqare values were highly significant in each cross indicating a discrepancy between the observed and expected generation means. The observed and expected generation means are listed in Table 12. The P1 observed values were consistently close to the expected values. However, the differences between observed and expected values of the remaining generations were variable. This indicates that fitting the additive-dominance model will not accurately predict generation means, and that the estimates of m, a, and d are biased to an unknown extent by factors other than additive and dominance gene action (Mather and Jinks, 1971). Transformations to a logarithmic

Table 11

Mean estimates of the three-parameter model for pericarp thickness

Parameter	AA8 X CI21E	AA8 X B68	AA8 X H55	677a X B68	677a X B37	677a X H55
m	72.4**	87.9**	66.6**	85.9**	79.1**	62.9**
a	-19.6**	-33.1**	-10.9**	-38.9**	-29.4**	-14.7**
d	-12.6**	-21.3**	-17.8**	-12.0**	-3.6	-7.5**
Chi^2	222.2**	85.7**	131.7**	190.2**	89.5**	435.8**
m^a	1.84**	1.92**	1.82**	1.89**	1.86**	1.78**
a	-0.13**	-0.18**	-0.08**	-0.22**	-0.18**	-0.11**
d	-0.06**	-0.10**	-0.13**	-0.01**	0.02	-0.04**
Chi^2	125.1**	52.2**	63.5**	142.6**	78.5**	232.4**
m^b	8.43**	9.26**	8.15**	9.05**	8.72**	7.87**
a	-1.20**	-1.88**	-0.71**	-2.23**	-1.71**	-0.97**
d	-0.67**	-1.10**	-1.17**	-0.40**	0.01	-0.40**
Chi^2	165.2**	68.1**	91.8**	166.4**	84.7**	315.4**

[a] Commom logarithmic transformation.

[b] Square root transformation.

Table 12

Values for the observed generation means and the expected generation means derived from the joint scaling test

Generations	AA8 X CI21E		AA8 X B68		AA8 X H55		677a X B68		677a X B37		677a X H55	
	OGM[a]	EGM[b]	OGM	EGM	OGM	EGM	OGM	EGM	OGM	EGM	OGM	EGM
P1	54.6	52.8	54.6	54.8	54.6	55.7	50.5	47.1	50.5	49.7	50.5	48.2
P2	98.5	92.0	132.3	121.1	82.0	77.5	132.3	124.8	107.8	108.4	82.0	77.6
F1	68.9	59.8	68.6	66.6	51.3	48.7	81.1	73.9	77.1	75.5	61.4	55.5
F2	58.9	66.1	74.7	77.3	60.0	57.6	61.3	79.9	62.1	77.3	52.1	59.2
B1	51.2	71.8	63.5	60.7	57.6	73.6	52.2	62.5	63.5	71.4	49.6	76.8
B2	73.3	75.9	78.8	93.8	54.2	63.1	103.1	99.4	102.6	92.0	61.1	66.6

[a] OGM = Observed Generation Mean.

[b] EGM = Expected Generation Mean.

scale (Table 11) reduce the chi-square values to greater extent than the square root transformation; however, the chi-square values still are significant.

Since the chi-square values were significant, the six parameter model (Hayman; 1958, 1960) using the notations of Gamble (1962) was applied to all of the crosses to detect whether or not any non-allelic interactions exist that were not indicated by the A, B, C scaling test. The six gene effects were: 1) the F2 mean (m), 2) an additive genetic component (a), 3) a dominance genetic component (d), 4) an additive x additive genetic component (aa), 5) an additive x dominance genetic component (ad), and 6) a dominance x dominance genetic component. Finding significance of the aa, ad, and dd parameters would be similar to finding significant deviations from 0 in the A, B, C scaling test (Mather and Jinks, 1971). The mean estimates of the six-parameter model for pericarp thickness are shown in Table 13. In agreement with the A, B, C scaling test, there was no detection of epistasis in every cross. The mean was found to be significantly different from 0 in all crosses, however additive effects were found to be significant only in two crosses (677a X B68 and 677a X B37). No dominance effects were detected in this model. Since the A, B, C scaling test and fitting the six parameter model indicated that there were no epistatic effects, it may be concluded that non-allelic interactions are not present in each of the crosses.

The variances around the mean pericarp thickness of each generation in the six crosses are presented in Table 14. With the exception of H55, the P2 variances were larger than the P1 variances. The F1

Table 13

Mean estimates of the six-parameter model for pericarp thickness

Parameter	AA8 X CI21E	AA8 X B68	AA8 X H55	677a X B68	677a X B37	677a X H55
m	58.8**	74.7**	59.9**	61.3**	62.1**	52.1**
a	-22.1	-15.3	3.4	-50.9*	-39.1**	-11.4
d	6.0	-38.9	-33.0	55.4	81.9	8.2
aa	13.6	-14.0	-16.0	65.6	83.9	13.0
ad	-0.2	23.5	17.0	-10.0	-10.5	4.3
dd	28.1	53.6	31.8	-31.4	-103.7	20.9

Table 14

Variances around the mean pericarp thickness (Table 9) of parents, F1, and advanced generations

Crosses	P1	P2	F1	F2	B1	B2
AA8 X CI21E	76.57	155.97	92.14	203.66	103.20	84.62
AA8 X B68	76.57	164.82	30.74	173.12	117.09	162.80
AA8 X H55	76.57	50.97	50.52	142.43	150.44	65.28
677a X B68	103.34	164.82	55.60	204.25	164.39	268.86
677a X B37	103.34	147.09	96.95	294.96	116.33	209.98
677a X H55	103.34	50.97	44.11	98.98	209.98	84.66

variances in most of the crosses are substantially larger than the P1 variances. There are several crosses where the parental variances are greater than the backcross variances. This is partially due to the difficulties encountered in measuring pericarp thicknesses of the inbreds. With the exception of H55, the kernels were small, of variable sizes, and the pericarps of the thick pericarped inbreds were slightly curled inwards resulting in some fluctuations in pericarp thickness measurements. It was observed during data collection that the pericarps of the advanced generations were more like that of the F1 than that of the inbreds. Considering this, the environmental variance for pericarp thickness may best be estimated using the F1 variance only. The backcross variances exceeded the F2 variance in the crosses 677a X B68 and 677a X H55, suggesting that the F2 sample size may not have been great enough to accommodate the extreme pericarp thickness values.

The components of genetic variances were estimated under the assumption of no epistasis and no linkage, and are presented in Table 15 along with heritability estimates. There is no consistency for the values of any one component of variation among the crosses. Generally the additive variances (V_A) were much larger than the dominance variance (V_D) except in the case of 677a X B68 where a negative value is shown (negative variances are interpreted as 0). Negative or small dominance variances were the result of the large environmental variances (V_E) and the small F2 variances. The large environmental variances were mostly due to the parents rather than the F1's.

The narrow sense heritability estimates derived by Warner's (1952) and by the conventional formula (negative variances considered

Table 15

Genetic variances and heritability estimates for pericarp thickness

Crosses	Genetic Variances[a]			Heritability Estimates		
	V_A	V_D	V_E	nh^2[b]	nh^2[c]	bh^2[d]
AA8 X CI21E	219.50	-124.08	108.23	107.78	66.97	66.97
AA8 X B68	66.36	16.05	90.71	38.33	38.33	47.60
AA8 X H55	69.14	13.93	59.36	48.55	48.55	58.32
677a X B68	-24.75	121.08	107.92	-12.12	0.00	52.87
677a X B37	263.62	-84.45	115.79	89.37	69.48	69.48
677a X H55	33.30	-0.47	66.14	33.65	33.49	33.49
Average[e]	108.65	25.18	91.36	50.93	42.80	54.78

[a] V_A = additive variance, V_D = dominance variance, V_E = environmental variance.

[b] Narrow sense heritability obtained by Warner's (1952) formula: $nh^2 = (2VF_2 - VB_1 - VB_2)/VF_2$

[c] Narrow sense heritability obtained by the conventional formula. $nh^2 = V_A/(V_A + V_D + V_E)$; negative variances considered as 0.

[d] Broad sense heritability obtained by the conventional formula: $bh^2 = (V_A + V_D)/(V_A + V_D + V_E)$; negative variances considered as 0.

[e] Average values for V_A and V_D were obtained considering negative variances to be 0.

as 0) are similar when all of the components of variances are positive. However, when V_D is negative, Warner's (1952) formula provides heritability estimates that are larger than the conventional formula. This is due to the fact that when negative values are considered as 0, the values for the total phenotypic variation in the conventional formula become larger than the actual F2 variances. Generally, the broad sense heritability estimates were not substantially larger than the narrow sense heritability estimates due to the small or 0 dominance variance. Where the dominance variances were 0, the broad sense heritability estimates were equal to the narrow sense heritability estimates in the conventional formula and were less than the estimates derived from Werner's (1952) formula. The average narrow sense heritability estimates were 50.9% for Warner's formula and 42.8% for the conventional formula which are not significantly different from each other.

Earlier it was argued that the F1 variances should be used as the estimates of the environmental variances. Values for variance components and heritability estimates when $V_E = VF_1$ are shown in Table 16. The narrow sense heritability estimates were estimated by the conventional formulas. The values of V_D increased due to the reduction of the V_E values. The values for the narrow sense heritability estimates are similar to those in Table 15, however, the broad sense heritability estimates were greatly increased. This increase was expected since the reduced V_E values decrease the total phenotypic variation, and increase the values of V_D.

Further estimations of broad sense heritability are derived through three formulas. These estimates are presented in Table 17 along

Table 16

Genetic variances and heritability estimates for pericarp thickness considering the F1 variance as V_E

Crosses	Genetic Variances			Heritability Estimates	
	V_A	V_D	V_E	nh^2[a]	bh^2[b]
AA8 X CI21E	219.50	-107.98	92.14	70.40	70.40
AA8 X B68	66.36	76.02	30.74	38.33	82.24
AA8 X H55	69.14	22.77	50.52	48.50	64.45
677a X B68	-24.75	173.40	55.60	0.0	75.72
677a X B37	263.62	-65.61	96.95	73.11	73.11
677a X H55	33.30	21.57	44.11	33.64	55.43
Average	108.65	48.96	61.68	44.00	70.23

[a] $nh^2 = V_A/(V_A + V_D + V_E)$

[b] $bh^2 = (VF_2 - VF_1)/VF_2$

Table 17

Estimates of broad sense heritability
through five different methods

Cross	bh^2[a]	bh^2[b]	bh^2[c]	bh^2[d]	bh^2[e]	Average
AA8 X CI21E	66.97	70.40	48.83	46.34	42.91	55.09
AA8 X B68	47.60	82.24	56.26	35.11	30.28	50.30
AA8 X H55	58.32	64.45	59.88	56.14	55.23	59.00
677a X B68	52.87	75.72	53.57	36.10	34.36	50.52
677a X B37	69.48	73.11	62.34	58.20	57.55	64.20
677a X H55	33.49	55.43	38.74	26.67	22.05	45.71
Average	54.79	70.23	53.27	43.09	40.40	53.92

[a] $bh^2 = (V_A + V_D)/(V_A + V_D + V_E)$, ref. Table 15

[b] $bh^2 = (VF_2 - VF_1)/VF_2$, ref. Table 16

[c] $bh^2 = VF_2 - \frac{1}{4}(VP_1 + VP_2 + 2VF_1) / VF_2$

[d] $bh^2 = (VF_2 - \sqrt{VP_1 \times VP_2})/VF_2$

[e] $bh^2 = [VF_2 - \frac{1}{2}(VP_1 + VP_2)]/VF_2$

with the estimates from the conventional formula (Table 15) and the formula in Table 16 for comparison. The difference between these formulas is that each formula has a different method of calculating V_E. Estimates from the first three formulas (columns 1, 2, and 3) are larger than estimates from the last two formulas (columns 4 and 5) due to the inclusion of the F1 in the numerator which increases its value. Formulas 1 (column 1) and 3 (column 3) provide estimates which are similar in magnitude due to the use of all three nonsegregating generations in the estimation of V_E. Formula 2 which uses only the F1 variance as the estimate of V_E provides the highest estimates of broad sense heritability. Formulas 4 and 5 provide the lowest estimates since only the parental variances are used, and the variances are large in comparison to the F1. It should be noted that when all three nonsegregating generations have similar variances, the values for all five formulas are similar as in AA8 X H55.

Estimates of the minimum number of effective factors) heritable units) were made through the use of four different formulas and are presented in Table 18. There was no consistency in the estimates of the number of effective factors in all of the crosses. The average number of effective factors from the four formulas for each of the crosses indicates that there are 1.2 to 7.1 effective factors governing pericarp thickness. The high estimates obtained by Weber's formula were due to the inclusion of the P1 and P2 variances in the denominator (formulas 3 and 4) which would decrease the magnitude of the estimates since the parental variances were much larger than the F1 variances in most cases. Where the F1, P1, and P2 variances are similar, the

Table 18

Estimations of the minimum number of effective factors controlling pericarp thickness

Cross	E.F.	E.F.	E.F.	E.F.	Average
AA8 X CI21E	2.2	2.3	2.5	2.4	2.4
AA8 X B68	5.3	6.4	9.1	7.5	7.1
AA8 X H55	1.1	1.8	1.1	1.1	1.2
677a X B68	5.6	5.8	8.7	7.9	7.0
677a X B37	2.1	2.1	2.3	2.3	2.2
677a X H55	2.3	2.4	3.8	3.3	3.0
Average	3.1	3.5	4.6	4.1	3.8

[a] $E.F. = (\overline{P_1} - \overline{P_2})^2/8(VF_2 - VF_1)$

[b] $E.F. = (0.75 - h + h^2)(\overline{P_1} - \overline{P_2})^2/4(VF_2 - VF_1)$

where $h = (\overline{F_1} - \overline{P_1})/(\overline{P_2} - \overline{P_1})$

[c] $E.F. = (\overline{P_1} - \overline{P_2})^2/8(VF_2 - \sqrt[3]{VP_1 \times VP_2 \times VF_1})$

[d] $E.F. = (\overline{P_1} - \overline{P_2})^2/8[VF_2 - (VP_1 + VP_2 + VF_1)/3]$

estimates of the number of effective factors are similar for all four formulas. This would also be the case if the F1 variance was intermediate to that of the parents.

1.4.2.2 Evaluation of the Effects of + and su Endosperm Genotypes on Pericarp Thickness

Pericarp thickness measurements on + and su types of kernels indicated that pericarp thickness is not affected by the underlying endosperm in the F1 crosses between sweet corn and field corn inbred lines (Table 19). The values for both endosperm genotypes are similar regardless of the position measured on the pericarp. This is confirmed by the insignificant mean square for endosperm in Table 20. Significant differences were also detected between hybrids and between positions tested. There is also a significant hybrid by position interaction mean square which is illustrated in Figure 7. This interaction was due to the two crosses AA8 X CI21E and AA8 X H55 where the abgerminal position was not greater than the germinal position.

1.4.2.3 Discussion

Information on the mode of inheritance and gene actions on pericarp thickness have been of interest during the past decade since the discoveries of its important effects on the general quality of maize including tenderness of sweet corn, popping ability of popcorn, water movement from the kernel, and resistance to pathogens. The nature of gene actions and heritability estimates are important in determining the best breeding method to modify a quantitative trait such as pericarp thickness.

Table 19. -- Statistics of dispersion for pericarp thickness in microns for kernels of the su and + types of endosperm from the same hybrid ear from the generation mean crosses

Position	Endosperm	$\bar{x}$	s	$s_{\bar{x}}$	C.V.	n[a]
Germinal	su	63.0	11.91	0.38	18.92	984
	+	62.3	11.31	0.36	18.16	971
Abgerminal	su	71.8	19.29	0.61	26.86	984
	+	71.5	17.20	0.55	24.06	971
Average	su	67.4	16.52	0.38	24.67	1968
	+	66.9	15.27	0.35	22.82	1942

[a] A close approximate of the number of ears measured for each endosperm type is n in the Average row divided by 10.

Table 20

Analysis of variance for pericarp thickness in microns for su and + endosperm types, hybrids, and positions in Table 18

Source	df	Mean Square
Endosperm (E)	1	240.0
Position (P)	1	79568.0***
Hybrids (H)	6	61237.3***
E X P	1	16.0
E X H	6	402.6
P X H	6	12328.0***
E X P X H	6	205.3
Sampling Error	768	438.4***
Subsampling Error	3114	42.9

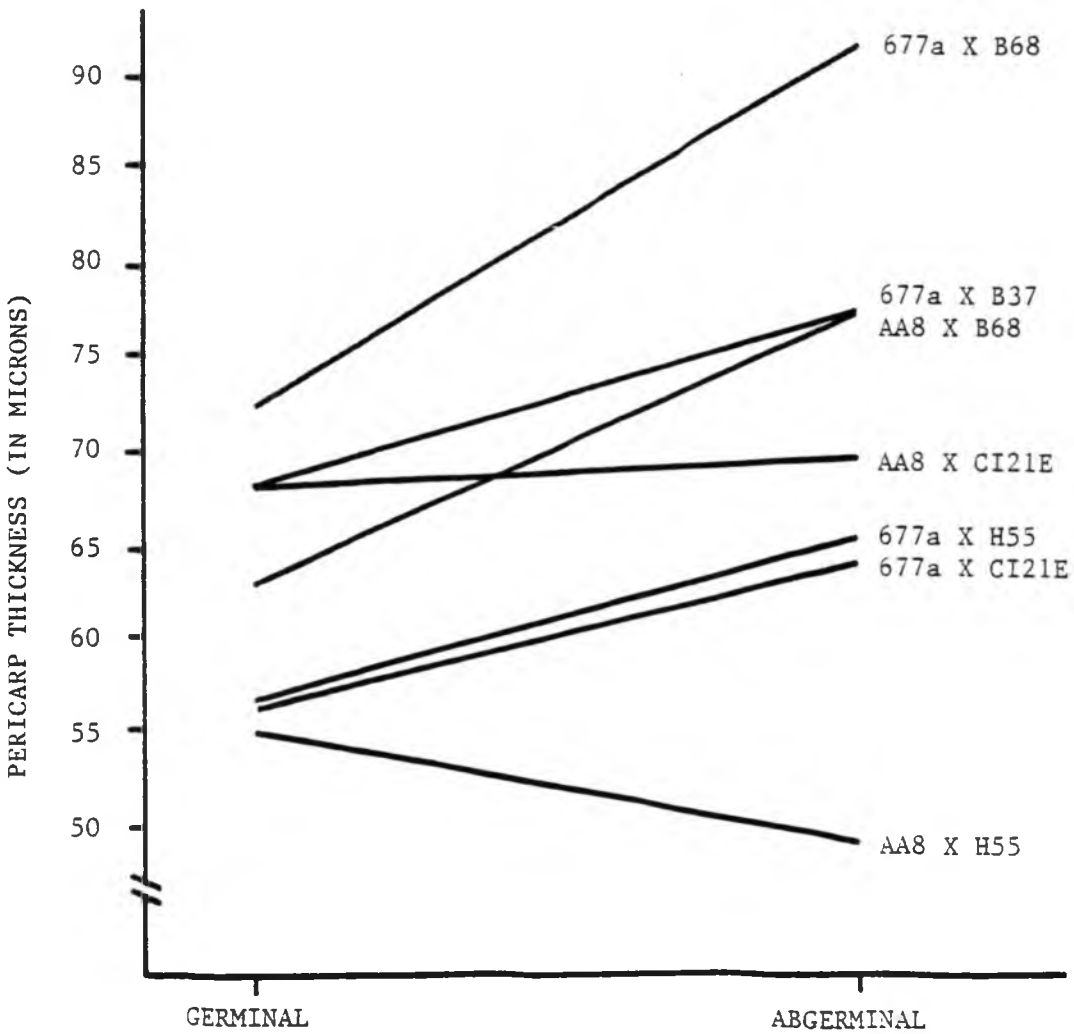

Figure 7. Mean pericarp thickness for germinal and abgerminal positions on the pericarp for hybrids from the generation mean analysis

The results in this study agree with those of Helm and Zuber (1972a) and Ho et al. (1975) where pericarp thickness was found to be quantitative in nature and not controlled by a single gene with a modifier complex which was concluded by Richardson (1960) in popcorn. In this study, the significant dominance genetic component, and the skewness of the F2 distributions and the direction of the F1 means towards the thin pericarped parent indicated that genes for thin pericarps are dominant. This is in agreement with all of the previous studies which have shown that dominant genes control thin pericarps.

It was observed that the F1 mean was less than that of the thin pericarped parent in only one of the crosses, AA8 X H55. Helm and Zuber (1972a) found negative line heterosis effects in H55 (-13 microns) for thin pericarps which may account for the F1 of the AA8 X H55 cross having thinner pericarps than the AA8 parent. They also indicated that crosses involving H55 as a parent would produce F1's that would have thinner pericarps than expected on the basis of the pericarp thickness of H55.

A disagreement exists between this study and previous studies (Helm and Zuber, 1972a; Ho et al., 1975) regarding the presence of epistasis. Previous studies have indicated that epistatic effects were significant in determining pericarp thickness. Helm and Zuber (1972a) found significant additive x additive (aa) effects whereas Ho et al. (1975) found significant dominance x dominance (dd) effects. In this study epistatic effects were determined to be insignificant by the A, B, C scaling test and by fitting the six-parameter model. However, the three-parameter joint scaling test suggests that epistatic effect not detected by the A, G, C scaling test and by fitting the six-parameter

model may be present. It is also possible that this discrepancy may alleviated by increasing the sample size. It should be pointed out that since these are theoretical models, the data obtained may not always conform to these models and suitable scales are not always obtained through transformations.

The narrow sense heritability estimate obtained in this study was lower than the 80% estimate obtained by Helm and Zuber (1972a) and the 72% estimate obtained by Ho et al. (1975) through the method of regression of offspring on midparental value. However, this method may not yield similar results obtained from a generation mean analysis. Three narrow sense heritability estimates were obtained in this study. The estimate derived from Warner's (1952) formuls will be used since his method is widely used and the estimates from the other two formulas are not very different from that obtained from Warner's formula. Using Warner's formula, a narrow sense heritability estimate of 51% was derived from all of the crosses studied. Although less than that of the previous studies, a 51% narrow sense heritability estimate is high enough to suggest that selection for a desired pericarp thickness would result in favorable genetic advance.

Genetic advance can be predicted by the formula $G_s = i(V_p)^{\frac{1}{2}}nh^2$ (Brewbaker, 1964), where i is the standardized selection differential, V_p is the total phenotypic variance, and nh^2 is the narrow sense heritability estimate. If selection is based on a 10% selection intensity, then i is associated with a value of 1.7 (Brewbaker, 1964). Using the average values from Table 15 for V_p ($V_p = V_A + V_D + V_E$) and nh^2 (Warner's formula), genetic advance through seleciton form the F2 population would

result in 13.0 microns per genration. Selection for pericarp thickness in 'Hawaiian Super-sweet No. 9' resulted in an average decrease of 8 microns (disregarding cycle 1) per generation when selecting for thin pericarps (Section 1.4.1). This value is not inconsistent with the predicted value from the generation mean analysis.

Estimates of the average number of effective factors from Table 16 indicated that approximately 1 through 7 effective factors are responsible in determining pericarp thickness. Seven effective factors were observed for the crosses with B68 as a parent. The remaining four crosses contained 1 through 3 effective factors. This is considered to be relatively few and substantiates the fact that rapid gains in selection for pericarp thickness are likely.

The conclusion can be drawn that the genetics of pericarp thickness are complicated since there is no concrete agreement between any of the studies on pericarp thickness concerning epistatic effects. Since additive gene effects were found to be the most important in determining pericarp thickness and high heritability estimates were found for this trait, a mass selection breeding program should result in significant progress for a desired thickness. Due to dominance gene effects for thin pericarps, selection for thin pericarps should result in greater progress than when selecting for thick pericarps. Dominance for thin pericarps may not be universal since Helm and Zuber (1972a) observed that Mo940 crosses had thicker pericarps than expected. In studies of Helm and Zuber (1972a) and Ho et al. (1975), there were significant line effects indicating that in mating schemes a desired pericarp thickness can be acquired by selection of lines that were tested for the desired effect.

1.4.3 Evaluation of Sweet Corn Hybrids for Pericarp Thickness at Two Locations

1.4.3.1 Results

Ten major sweet corn hybrids grown commercially in the U.S. were evaluated for temperature effects on pericarp thickness at the locations of Lalamilo and Waimanalo. Silver Queen was evaluated at the sweet corn stage and at maturity at Waimanalo only and Sweet Sue was analyzed at Lalamilo only. The mean pericarp thickness for each hybrid is presented in Table 21. The Duncan's BLSD in the combined analysis for locations indicated that Jubilee, Stylepak, and Bonanza had the thinnest pericarps and therefore should produce the most tender ears relative to the other hybrids. Jubilee and Stylepak were consistently among the hybrids with the thinnest pericarps throughout all of the experiments conducted. Bonanza was comparatively thick at Lalamilo. Gold Winner and Midway consistently had the thickest pericarps in every experiment. They combined location means of these two hybrids are well separated from the other hybrids as is indicated by the Duncan's BLSD. On the basis of pericarp thickness, Gold Winner and Midway would be predicted to produce comparatively tough ears.

Generally, all of the hybrids were thinner in pericarp thickness at sweet corn stage than at maturity (Table 21). Silver Queen and Sweet Sue were among the thin pericarped hybrids. However, at maturity Silver Queen had thicker pericarps than was expected. No conclusions could be made about Sweet Sue at maturity.

The mean squares in Table 22 indicate that there is a significant maturity x hybrid interaction at the 5% level which suggests that

Table 21

Mean pericarp thickness in microns for the major sweet corn hybrids in the U.S. grown at two locations

Hybrids	Locations						Waimanalo and Lalamilo[b]	
	Waimanalo[a]		Waimanalo[b]		Lalamilo[b]			
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Jubilee	39.4	7.66	41.9	6.58	39.0	7.15	41.1a	6.31
Stylepak	41.8	11.48	44.6	10.00	34.8	11.59	42.0a	11.18
Bonanza	37.5	7.96	43.8	6.85	46.7	11.75	44.7ab	8.53
H68	47.4	11.25	49.3	14.86	44.5	10.58	47.6ab	12.67
NK51036	45.3	8.61	50.4	8.03	44.4	6.97	48.2bc	7.97
Iobelle	36.5	9.29	55.1	9.78	40.2	10.37	50.0c	12.02
GCB (N)	42.4	10.23	54.4	8.95	42.4	9.52	50.2c	10.13
GCB (T)	46.5	9.59	54.9	6.91	42.9	9.50	50.9c	9.18
Midway	49.6	10.07	57.4	10.19	51.1	11.88	55.3d	10.47
Gold Winner	48.6	9.27	58.3	9.15	55.4	10.50	57.3d	9.01
Silver Queen	39.4	10.46	53.5	9.27	-	-		
Sweet Sue	36.9	8.68	-	-	41.3	8.96		

[a] Means represent data from ears at sweet corn stage (approximately 20 days after pollination)

[b] Means represent data from ears at maturity.

pericarp thickness at the sweet corn stage cannot be predicted accurately from measuring pericarp thickness at maturity or vice versa. As was expected there were highly significant differences beween hybrids and between positions. The sampling error was also significant indicating that there was greater between ear variation than within ear variation.

The analysis of variance of hybrids evaluated at different locations (Table 23) indicated that positions and hybrids are highly significant. Since there were no interactions between positions with other factors, differences between positions were consistent regardless of where the sweet corn hybrids were grown or the hybrid from which the pericarps were taken from. A significant interaction between hybrids and locations was detected at the 5% level which suggests that hybrids may change in pericarp thickness with differing climatic conditions. The major contributors to this significant interaction were the hybrids Iobelle, GCB (N), and GCB (T) (Table 21).

It is possible that the differences in the positions measured could contribute to the interaction between hybrids and locations since four positions were measured on pericarps from hybrids grown at Lalamilo and two positions were measured on pericarps from hybrids grown at Waimanalo. Therefore, an analysis was conducted using only the measurements at the base of the germinal and abgerminal sides of the pericarps (Table 24). Except for H68, it was apparent that there were no differences between the means using four positions or two positions at the base (from the same set of data from hybrids grown at Lalamilo). Generally, the base of the pericarp is thicker than at the top, however, in the case of these hybrids it made no difference. Thus, the data obtained at Lalamilo and at Waimanalo should be comparable.

Table 22. -- Analysis of variance for pericarp thickness in microns of the major sweet corn hybrids evaluated at sweet corn stage and at maturity in Table 21

Source	df	Mean Square
Maturity (M)	1	54104.0
Replications in Maturity	2	3666.0
Positions (P)	1	44672.0***
M X P	1	496.0
Error b	2	324.5
Hybrids (H)	10	7422.3***
M X H	10	1397.9*
P X H	10	558.8
M X P X H	10	417.0
Error c	40	610.8
Sampling Error	792	157.0***
Subsampling Error	2300	32.8

Table 23

Combined analysis of variance for pericarp thickness in microns of the major sweet corn hybrids in the U.S. in Table 21

Source	df	Mean Square
Locations (L)	1	27062.0
Replications in Locations	2	1775.0
Position (P)	1	28980.0***
L X P	1	7.0
Error b	2	63.0
Hybrids (H)	9	7738.0***
L X H	9	2156.4*
P X H	9	732.7
L X P X H	9	176.33
Error c	36	1006.78
Sampling Error	720	143.6
Subsampling Error	2028	27.3

Table 24

Mean pericarp thickness in microns for mature kernels of sweet corn hybrids at Lalamilo

Hybrids	Lalamilo[a]	Lalamilo[b]
Jubilee	39.0	41.6
Stylepak	34.8	35.6
Bonanza	46.7	48.3
H68	44.5	51.8
NK51036	44.4	45.3
Iobelle	40.2	42.5
GCB (N)	42.4	45.9
GCB (T)	42.9	46.5
Midway	51.1	55.9
Gold Winner	55.4	59.3

[a] Means represent data from measuring 4 positions on the pericarp (top of the germinal and abgerminal side and bottom of the germinal and abgerminal side

[b] Means represent data from measuring the bottom of the germinal and abgerminal sides of the pericarp.

1.4.3.2 Discussion

All of the hybrids evaluated were found to have thin pericarps as breeders realize the importance of the pericarp on the palatibility of sweet corn. Even Gold Winner and Midway which were found to have the thickest pericarps were not exceptionally thick. The pericarp thickness measurements obtained from these hybrids were quite similar to that obtained after the third cycle of selection in 'Hawaiian Super-sweet No. 9'.

The hybrids tested, with the exception of Iobelle and both GCB's seemed to be buffered against temperature effects on pericarp thickness. It may be possible that the cool temperatures at the higher elevation affect the enzymes responsible for the development of the pericarp, and some lines of sweet corn are susceptible or resistant to the effect.

The fact that some hybrids produce thicker pericarps at maturity could be put into some practical use. Generally, seeds with thin pericarps are subject to pericarp breakage which affects viability of the seeds and the ability of the seedlings to resist pathogens. It may be possible that inbreds can be developed for this characteristic of producing thin pericarps at sweet corn stage and thick pericarps at maturity. The result would be seeds of high germination percentages and ears that are tender to the palate.

As in the selection experiment (Section 1.4.1), it was observed that the differences in pericarp thickness between positions (germinal and abgerminal) were consistent regardless of locations or the hybrids tested. Future experiments evaluating pericarp thickness of sweet corn

hybrids need to utilize measurements on one position only to obtain comparable results.

1.4.4 Survey of Pericarp Thickness in Some of the Races of Maize

A survey of 85 races of maize for pericarp thickness was conducted. The mean pericarp thickness values for each race are presented in Table 25. Races are listed in alphabetical order. Multiple samples of some of the races were taken since they differed by a second name describing kernel characteristics, or because they were from different seed lots. Samples within races that were multiply sampled often differed significantly. These include the Avati's, Caingang, Chococeno's, Pira's, Pollo's and Puya's. Multiple measurements within races were similar in thickness for Clavo E and F, Comun's, Conico's, Confite's, Costeno's and Puya Blanco (measured twice from the same seed lot). Generally, this was expected since races are grouped according to similar morphological, anatomical, and physiological characteristics.

Some of these mutliple samples show wide differences although they were of a similar race. These include the Chococeno's, Pira's, Pollo Amarillo, and Puya's. It was unexpected that two samples of Pollo Amarillo from two different seed lots would be different in pericarp thickness. It is possible that improvements undertaken or small seed samples taken in maintaining the race could lead to genetic drift in pericarp thickness. Seed samples from different versions of lines can differ greatly in pericarp thickness. Helm and Zuber (1970) reported that B37 had pericarp thickness of about 160 microns, whereas the thickness obtained for B37 (at University of Hawaii, a conversion line) in the generation mean analysis (Section 1.4.2) was about 102 microns.

Table 25

Mean pericarp thickness in microns
of the races of maize

Races	Germinal $\bar{x}$	Germinal s	Abgerminal $\bar{x}$	Abgerminal s	t^a	Average $\bar{x}$	Average s
Alazan	72.7	8.53	96.0	9.80	-5.92**	84.3	18.56
Amagaceno Mezcla	78.7	8.87	67.4	8.21	4.44**	73.0	13.64
Andaqui Blanco	91.5	9.56	84.4	9.18	1.47	87.9	18.97
Argentino	66.5	8.15	84.6	9.20	-6.69**	75.6	12.50
Arrocillo	53.9	7.34	53.9	7.34	-0.01	53.9	11.45
Avati Diakaira	75.6	8.70	71.2	8.44	1.52	73.4	9.63
Avati Morati	89.2	9.45	78.5	8.86	2.34	83.9	15.90
Avati Tupi	70.9	8.42	51.4	7.17	5.11**	61.1	17.28
Bolita	61.0	7.81	89.1	8.89	-5.73**	70.0	15.40
Bolivian Interlocked Corn	50.9	7.13	51.9	7.20	-0.49	51.4	7.80
Cacahuacintle	79.5	8.92	83.4	9.13	-1.04	81.4	13.87
Cabuya Amarillo	102.8	10.14	84.1	9.17	2.95*	93.5	23.70
Cacao	64.6	8.04	61.4	7.83	0.67	63.0	17.23
Cacao Amarillo	112.6	10.61	83.9	9.16	6.31**	98.2	21.60
Caingang	98.6	9.93	81.1	9.00	5.10**	89.8	16.74
Caingang	68.9	8.30	71.8	8.48	-0.07	70.4	14.13
Calibaqui	89.4	9.45	80.7	8.98	2.20*	85.1	14.30
Canilla	76.5	8.74	87.0	9.33	-1.97	81.7	18.23
Canario de Ocho	71.0	8.43	76.2	8.73	-2.21*	73.6	10.43
Cariaco	97.2	9.86	98.2	9.91	-0.20	97.7	18.36
Cateto Mezcla	67.2	8.20	76.2	8.83	-1.92	71.1	16.00
Cateto Paulista	91.8	9.58	73.4	8.64	3.13**	83.2	20.22
Celeya	77.2	8.79	83.8	9.15	-1.49	80.5	13.48
Chalqueno Puebla	60.8	7.70	84.4	9.19	-8.08**	72.6	16.31
Chandelle	69.8	8.36	75.4	8.69	-0.98	72.6	17.71
Chapalote	77.4	8.80	79.0	8.89	-0.40	78.2	13.25
Chirimito	45.0	6.71	54.0	7.35	-2.83*	49.5	9.23
Chococeno	82.1	9.06	75.9	8.71	1.62	79.0	13.78
Chococeno Harinoso	47.7	6.90	37.2	6.10	4.49**	42.5	10.79
Chococeno Segregacionces	67.9	8.24	47.3	6.88	11.76**	57.6	14.08
Cholito	38.4	6.20	43.8	6.62	-2.10*	41.1	8.80
Clavo D	98.9	9.95	88.1	9.39	2.18	93.5	19.35
Clavo E	67.4	8.12	64.1	8.00	1.08	65.8	13.18
Clavo F	67.2	8.20	63.8	7.99	0.94	65.5	13.30
Coastal Tropical Flint	74.6	8.64	86.6	9.31	-3.67**	80.6	11.32
Comiteco	58.1	7.63	68.2	8.26	-2.26	63.2	13.96
Comun Amarillo	90.8	9.53	83.0	9.11	2.24*	86.9	11.81
Comun Blanco	69.8	8.36	75.3	8.68	-0.94	72.6	17.35
Comun Segregacionces	60.8	7.80	66.9	8.18	-1.09	63.9	17.41
Confite Morocho	63.7	7.98	66.9	8.36	-1.19	66.8	16.80
Confite Puntiagudo	51.1	7.15	62.7	7.92	-3.22**	56.9	12.85
Conico	60.1	7.75	59.4	7.71	0.30	59.8	8.40

Table 25. (continued) Mean pericarp thickness in microns of the races of maize

Races	Germinal $\bar{x}$	Germinal s	Abgerminal $\bar{x}$	Abgerminal s	t[a]	Average $\bar{x}$	Average s
Conico Norteno	60.5	7.78	69.2	8.32	-2.48**	64.8	13.96
Costeno Amarillo	67.3	7.98	69.0	8.31	-1.27	66.4	13.65
Costeno Blanco	59.4	7.71	63.1	7.94	-1.06	61.2	11.63
Costeno Segregacionces	64.8	8.05	70.3	8.38	-1.02	67.5	15.98
Cuban Flint	75.0	8.66	93.8	9.68	-4.68**	88.4	17.01
Dzit Bacal	54.9	7.41	69.8	8.35	-3.75**	62.3	15.64
Early Carribean	99.0	7.20	109.9	10.84	-1.92	104.4	21.31
Enano	51.8	9.95	71.5	8.46	-3.89**	61.6	16.29
Guaribero	28.6	5.35	43.3	6.56	-3.59**	35.8	12.26
Guirua	92.9	9.64	92.1	9.60	0.19	92.5	14.15
Hatian Yellow	72.6	8.52	78.2	8.84	-1.53	75.4	11.32
Harinoso de Ocho	65.6	8.10	96.4	9.82	-5.56**	81.0	23.08
Huevito	65.1	8.07	84.6	9.20	-5.84**	74.9	14.27
Imbricado	78.1	8.84	84.9	9.21	-1.25	81.5	17.58
Jala	60.6	7.78	89.2	9.44	-7.82**	74.9	18.98
Maize Dulce	59.6	7.72	67.4	8.21	-2.35**	63.5	14.07
Montana	57.4	7.58	66.5	8.15	-3.23**	61.9	11.17
Morocho	73.8	8.59	90.2	9.50	-2.41*	82.0	18.21
Nal-Tel	75.9	8.71	74.8	8.65	0.25	75.3	14.70
Negrito	76.6	8.75	76.8	8.76	-0.05	76.7	13.00
Olotillo	69.2	8.32	76.5	8.74	-2.41	72.9	10.81
Palomero Toluqueno	122.6	11.07	110.7	10.52	1.94	116.7	22.35
Pardo	44.5	6.67	50.8	7.12	-2.42*	47.6	8.12
Perola	103.5	10.17	116.5	10.79	-1.49	110.0	31.22
Pira Blanco	113.3	10.64	115.0	10.72	-0.20	114.2	28.96
Pira Mezcla	61.2	7.82	57.4	7.58	0.80	59.3	16.32
Pisankalla	54.4	7.38	61.2	7.82	-5.19**	57.8	5.42
Pojoso Chico	44.4	6.64	53.0	7.28	-2.44**	48.5	11.51
Pollo Amarillo	99.5	9.98	85.3	9.35	2.33*	92.4	20.91
Pollo Amarillo	66.9	8.11	64.4	8.03	0.52	65.1	11.33
Pulcalpa	102.4	10.12	91.6	9.57	3.31**	97.0	11.00
Pulcalpa	84.6	9.20	98.8	9.94	-3.39**	91.7	17.36
Puya Amarillo	54.8	7.40	54.3	7.37	0.14	54.6	11.47
Puya Blanco	89.2	9.44	100.4	10.20	-1.53	94.8	23.90
Puya Blanco	53.4	7.30	53.8	10.02	-0.15	53.6	7.42
Puya Grande	88.2	9.39	96.9	9.84	-1.56	92.5	15.98
Quicheno	41.8	6.46	50.5	7.11	-4.30**	46.2	8.66
Reventador	60.1	7.75	64.4	8.02	-1.01	62.2	13.42
Sabanero Amarillo	86.0	9.27	84.2	9.84	-1.53	85.1	16.52
Salpor Tardio	58.5	7.65	72.4	8.51	-0.15	65.4	18.08
Salvadoreno	63.3	7.96	70.4	8.39	-3.76**	66.8	13.35
San Marceno	59.1	7.69	60.9	7.80	-0.49	60.0	20.38
St Croix	76.0	8.72	115.0	10.72	-5.20**	95.5	30.43

Table 25. (continued) Mean pericarp thickness in microns of the races of maize

Races	Germinal		Abgerminal			Average	
	$\bar{x}$	s	$\bar{x}$	s	t[a]	$\bar{x}$	s
Tehua	86.0	9.28	85.2	9.23	0.19	85.6	17.81
Tepecintle	55.2	7.43	71.3	8.44	-7.84**	63.3	17.20
Tuson	65.4	8.08	72.9	8.54	-1.95	69.1	17.88
Tusilla	65.0	8.06	78.6	8.86	-3.84**	71.8	18.11
Tuxpeno	104.1	10.20	102.2	10.11	0.25	103.1	24.16
Vandeno	75.2	8.67	70.6	8.40	1.19	72.9	16.57
Uchima	53.6	7.32	68.0	8.24	-4.57**	60.8	21.97
Yucatan	125.7	11.21	123.1	11.09	0.31	124.4	22.93
Zapalote Grande	56.0	7.48	52.9	7.27	0.63	54.5	31.41
Zapalote Chico	83.4	9.13	78.1	8.84	0.85	80.8	27.66

[a] t is the value for the t-test between the germinal and abgerminal positions

The t-tests between the germinal and abgerminal positions are presented in Table 25. Roughly half of the races showed no significant difference in pericarp thickness between the germinal and abgerminal positions. The negative signs indicate that the germinal position was of lesser magnitude than the abgerminal position and the positive numbers indicate the opposite.

No relation was observed for groups of races classified as closely related (Sprague, 1977) and their respective pericarp thickness. This indicates that pericarp thickness is independent of most of the morphological, physiological, and anatomical characteristics of the race. An example of related races of maize and their pericarp thicknesses are shown in Figure 7. These are groups of related races of maize in Mexico (Sprague, 1977). Races within cells are considered to be more closely related. Pericarp thickness varies widely within some of the cells suggesting that it is independently inherited. Consequently, providing that all races were maintained as isolated populations within a given environment, a specific pericarp thickness would occur for each particular race.

The races were also grouped into frequency distributions of five microns and the mean values, standard deviations, and coefficients are presented in Table 26. The races within each group are listed in alphabetical order. There is a wide variation in pericarp thicknesses which ranged from 35.8 microns to 124.4 microns. This source of variation may be useful in altering pericarps to desired thicknesses.

A significant mean square for interaction was observed for positions by races (Table 27). This is similar to the interaction noted for hybrids

Table 26

Frequency distribution of races into pericarp thicknesses of five microns

Race	$\bar{x}$	s	C.V.
36 - 40 microns			
1. Guaribero	35.8	12.26	34.23
41 -45 microns			
1. Chococeno Harinoso	42.5	10.79	25.40
2. Cholito	41.1	8.80	21.39
46 - 50 microns			
1. Chirimito	49.5	9.23	18.63
2. Pardo	47.6	8.11	17.04
3. Pojoso Chico	48.5	11.51	23.73
5. Quicheno	46.2	8.66	18.74
51 - 55 microns			
1. Arrocillo Amarillo	53.9	11.45	21.25
2. Bolivian Interlocked Corn	51.4	7.80	15.17
3. Puya Amarillo	54.6	11.47	21.02
4. Puya Blanco	53.6	7.42	13.86
5. Zapalote Chico	54.5	17.10	31.41
56 - 60 microns			
1. Chococeno Segregacionces	57.6	14.08	24.45
2. Confite Puntiagudo	56.9	12.85	22.59
3. Conico	59.8	8.40	14.05
4. Pira Mezcla	59.3	16.23	27.35
5. Pisankalla	57.8	5.42	9.38
6. San Marceno	60.0	12.22	20.38
61 - 65 microns			
1. Avati Tupi	61.1	17.28	28.26
2. Comiteco	63.2	13.96	22.10
3. Cacao	63.0	17.23	27.35
4. Comun Segregacionces	63.9	17.41	27.26
5. Conico Norteno	64.8	13.96	21.54
6. Costeno Blanco	61.2	11.63	18.99
7. Enano	61.6	16.29	26.43
8. Dzit Bacal	64.5	12.36	19.15
9. Maize Dulce	63.5	14.94	23.54
10. Montana	61.9	11.17	18.03
11. Pollo Amarillo	65.1	11.23	17.39

Table 26. (continued) Frequency distribution of races into pericarp thicknesses of five microns

Races	$\bar{x}$	s	C.V.
12. Puya Grande	65.4	18.08	27.64
13. Reventador	62.2	13.42	21.56
14. Salpor Tardio	65.4	7.96	12.17
15. Tehua	64.7	11.50	17.77
16. Tepecintle	63.3	10.89	17.21
17. Uchima	60.8	13.36	21.97
66 - 70 microns			
1. Bolita	70.0	15.40	21.99
2. Caingang	70.4	14.13	20.08
3. Clavo E	65.8	13.18	20.04
4. Clavo F	65.5	13.30	20.31
5. Confite Morocho	66.8	16.80	25.16
6. Costeno Amarillo	66.4	13.65	20.58
7. Costeno Segregacionces	67.5	15.98	23.67
8. Salvadoreno	66.8	8.92	13.35
9. Tuson	69.1	12.36	17.87
71 - 75 microns			
1. Amagaceno Mezcla	73.0	13.64	18.68
2. Avati Daikaira	73.4	9.63	13.11
3. Canario de Ocho	73.6	10.43	14.17
4. Cateto Mezcla	71.7	16.00	22.33
5. Chalqueno Puebla	72.6	16.31	22.46
6. Chandelle	72.6	17.71	24.38
7. Comun Blanco	72.6	17.35	23.90
8. Huevito	74.9	14.27	19.07
9. Hatian Yellow	75.4	11.32	15.01
10. Jala	74.9	18.98	23.34
11. Nal-Tel	75.3	14.70	19.51
12. Olotillo	72.9	10.81	14.84
13. Tusilla	71.8	13.01	18.11
14. Vandeno	72.9	12.08	16.57
76 - 80 microns			
1. Argentino	75.6	12.50	16.54
2. Chapalote	78.2	13.25	16.95
3. Celeya	80.5	13.48	16.75
4. Chococeno	79.0	13.78	17.45
5. Negrito	76.7	13.00	16.96
81 - 85 microns			
1. Alazan	84.3	18.56	22.01

Table 26. (continued) Frequency distribution of races into pericarp thicknesses of five microns

Races	$\bar{x}$	s	C.V.
2. Avati Morati	83.9	15.90	18.96
3. Cacahuacintle	81.4	13.87	17.03
4. Calibaqui	85.1	14.30	16.81
5. Canilla	81.7	18.23	22.31
6. Cateto Paulista	83.2	20.22	24.31
7. Coastal Tropical Flint	80.6	11.32	14.04
8. Cuban Flint	84.4	17.02	20.17
9. Harinoso de Ocho	81.0	23.08	28.50
10. Imbricado	81.5	17.58	21.57
11. Morocho	82.0	18.21	22.21
12. Sabanero Amarillo	85.1	16.52	19.42
13. Zapalote Grande	80.8	22.23	27.65
86 - 90 microns			
1. Andaqui Blanco	87.9	18.97	21.57
2. Caingang	89.8	16.74	18.63
3. Comun Amarillo	86.9	11.81	13.58
91 - 95 microns			
1. Cabuya Amarillo	93.5	23.70	25.36
2. Clavo D	93.5	19.35	20.69
3. Guirua	92.5	14.15	15.29
4. Pollo Amarillo	92.4	20.91	22.63
5. Puya Blanco	94.8	23.90	25.21
6. Puya Grande	92.5	15.98	17.27
96 - 100 microns			
1. Cacao Amarillo	98.2	21.60	21.99
2. Cariaco	97.7	18.36	18.79
3. Pulcalpa	97.0	11.00	11.34
4. St. Croix	95.5	29.07	30.43
101 - 105 microns			
1. Early Carribean	104.4	21.31	20.41
2. Tuxpeno	103.1	24.91	24.16
Greater than 106 microns			
1. Perola	110.0	31.22	28.39
2. Palomero Toluqueno	116.7	22.35	19.16
3. Pira Blanco	114.2	28.96	25.37
4. Yucatan	124.4	28.53	22.93

Table 27

Analysis of variance of the average pericarp thickness of the races in Table 25

Source	df	Mean Square
Races	97	14385.3***
Position	1	14384.0***
Races X Position	97	1599.8***
Sampling Error	4590	222.9

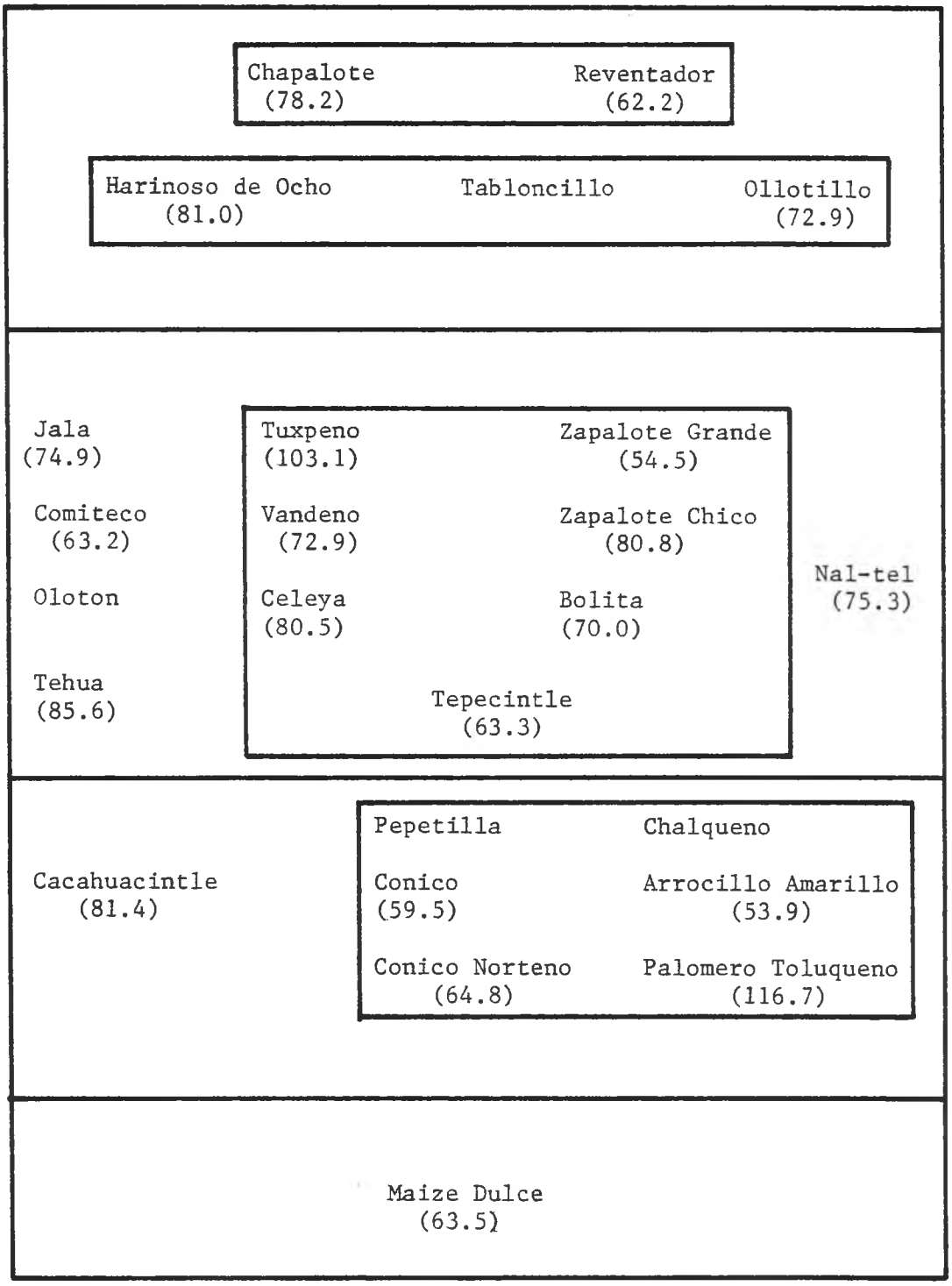

Figure 8. Pericarp thickness of the related races of the corn of Mexico (ref. Sprague, 1977).

and positions in the generation mean analysis (Section 1.4.2, Table 20). However, it is in contrast to the parallel behavior of positions observed in the selection experiment for thin pericarps in 'Hawaiian Super-sweet No. 9' and in the analysis of sweet corn hybrids in Sections 1.4.1 and 1.4.3 respectively. This suggests that some genetic factor may be responsible for the relative thickness of the germinal and the abgerminal positions. These two positions should be measured in the race collections to provide critical data in future analyses.

1.4.5 Pericarp Thickness of Various Endosperm Mutant Lines

1.4.5.1 Analysis of Mutants Converted to CM104

Fifteen mutants converted to the background of CM104 were analyzed for pericarp thickness. It was speculated that the underlying endosperm had no effects on pericarp thickness, hence, the mutants would be similar to the pericarp thickness of CM104.

The mean values, number of backcrosses, and chromosome location of the mutants are presented in Table 28. Mean pericarp thicknesses ranged from 55.7 microns for sh and 110.3 microns for sh2. It should be realized that sh is not related to sh2 from the difference in their locations on chromosomes. In a small separate experiment, sh2 and + (normal) kernels were taken off of the same ears and evaluated for pericarp thickness. The means were 102 microns for sh2 and 93 microns for +. This difference is not large and may be due to the pericarps being stretched out at maturity for the + kernels and wrinkled for the sh2 kernels. The difference between sh2 and + in Table 28 is much greater, which suggests the possibility of genes for thicker pericarps being linked to the sh2 mutant. It is also possible that pericarp thickness

Table 28. -- Average pericarp thickness, chromosome number, and number of backcrosses for 15 endosperm mutants and normal endosperm in the CM104 background

Mutants	Chromosome Number	Number of Backcrosses	$\bar{x}$	s	C.V.
sh2	3	3	110.3a	16.50	14.97
su2	6	2	86.5b	6.32	7.31
h	-	2	76.5c	7.88	10.29
bt2	4	3	73.3cd	10.85	14.79
sh4	5	2	73.3cd	8.90	12.15
f12	4	6	72.3cd	5.78	8.00
CM104	-	-	71.3de	6.07	8.51
du	10	4	69.7de	7.53	10.81
f1	2	5	69.3def	6.73	9.71
o2	7	2	67.3ef	5.11	7.59
o2b	7	4	66.0fg	6.70	10.14
su	4	2	65.3fg	6.57	10.06
wx	9	2	62.8g	5.87	9.35
bt	5	3	62.5g	8.63	13.80
o	4	3	61.8g	7.11	11.50
sh	9	2	55.7h	4.25	7.63

[a] Mean separation by Duncan's BLSD, 5% level (BLSD = 4.47)

of the original sh2 line was very thick and a greater number of backcrosses was needed to reduce the pericarp thickness to that of CM104 (+). Generally, the other mutants were not very distinct from the pericarp thickness of CM104 (+). The Duncan's BLSD indicated that there were no significant differences between CM104 (+) and bt2, sh4, f12, du, f1, and o2. However, it was suspected from the standard deviation of CM104 that the mean vlues of su (65.3 microns), o2b (66.0 microns) and h (76.5 microns) were not substantially different from the mean value of CM104 (71.3 microns). A few more backcrosses may be sufficient for pericarp thickness of these mutants to be close to that of CM104. Generally, most of the mutants with similar thicknesses to CM104 have been highly backcrossed into the CM104 background. The mutants with low number of backcrosses and yet similar thicknesses to CM104 may have had pericarp thicknesses similar to CM104 prior to backcrossing. This likelihood was not examined in this experiment. The other mutant lines dissimilar in thickness to CM104 may have had either much thicker or thinner pericarps prior to backcrossing and would require more backcrossing to equal the thickness of CM104.

It may be concluded that the type of endosperm does not affect pericarp thickness if the mutant lines are highly backcrossed into a particular line. Pericarp thickness seems to be inherited independently from the type of endosperm mutant. The exception to this case may be sh2 where linkage to thick pericarps is suspected.

1.4.5.2 Pericarp Thickness of o2 and + Endosperm Types in Various Inbred Lines

The second experiment was conducted to observe whether or not any

differences existed between o2 and + genotypes of the same inbred background. The inbreds evaluated were Ant2, B37, B68, CM105, CM111, Hi30, Mo17, and Oh43. The mean pericarp thicknesses of the + and o2 genotypes in the various inbred lines are presented in Table 29. Generally, the o2 and + lines were of similar pericarp thickness with the exception of Mo17 and B37. However, the Mo17o2 seedstock was obtained from University of Missouri, while the Mo17 used here was converted (5 backcrosses) in Hawaii to incorporate resistance to mosaic, which may account for the difference in their pericarp thicknesses. The B37 and Hi30 o2 lines were also conversions of 4-5 backcrosses.

Significant mean squares were obtained for the comparisons of B37, Hi30, Mo17, Oh43, and their counterpart o2 lines (Table 30). Two of these had thicker pericarps in the + version and two were thicker pericarps in the + version and two were thicker in the o2 version. The mean squares were very large for Mo17 and B37 + and o2 comparisons and is probably due to the reasons mentioned. Although differences in the other two lines (Mo17 and Oh43) were found to be highly significant, the mean squares (Table 30) are not very large. Mean differences of 8.1 and 6.2 microns were observed for the + and o2 genotypes of Hi30 and Oh43 respectively. Although statistically significant, it is suspected that the differences were due to the manner of sampling rather than to real differences between genotypes. The seeds were bulk sampled and a margin of error greater than that expected from uniform sampling from ears in a field experiment could have occurred. The interaction mean square for + and o2 genotypes in all lines compared was highly significant (Table 31) indicating that in some cases the + genotype was thicker and

Table 29

Mean pericarp thickness in microns of normal and o2 endosperm genotypes in 8 inbred lines

Inbred	$\bar{x}$	s	C.V.
Ant2	75.9	8.26	10.89
Ant2o2	80.2	11.25	14.02
B37	102.4	10.36	10.12
B37o2	117.4	14.46	12.32
B68	136.9	13.40	9.79
B68o2	130.5	17.82	13.65
CM105	66.2	11.36	17.16
CM105o2	65.3	6.85	10.49
CM111	63.3	7.25	11.44
CM111o2	62.7	10.81	17.23
Hi30	53.4	9.51	17.79
Hi30o2	65.3	11.16	17.09
Mo17	93.8	7.13	7.60
Mo17o2	49.8	5.40	10.85
Oh43	59.7	7.00	11.71
Oh43o2	47.5	7.14	15.04

Table 30

Mean squares for pericarp thickness of normal and o2 endosperm genotypes of inbred lines in Table 29

Inbreds	Mean Squares
Ant2(o2)	187.06
B37(o2)	2257.51***
B68(o2)	403.22
CM105(o2)	9.02
CM111(o2)	3.91
Hi30(o2)	1398.31***
Mo17(o2)	19360.00***
Oh43(o2)	1500.62***

Table 31

Combined analysis of variance of normal and o2 lines in Table 30

Source	df	Mean Square
Genotypes (+ vs o2)	1	1360.00***
Inbreds	7	31219.28***
Genotypes X Inbreds	7	3393.43***
Error	304	109.29

in other cases the o2 line was thicker. Most of this interaction appeared to be due to the differences between the B37 and Mo17 lines. Further field experiments should be conducted to determine whether there could be any real significant differences between the + and o2 lines.

1.4.5.2 Discussion

The results in this study agree with those of Helm and Zuber (1970) who measured pericarp thickness of various mutant conversions of B37 and Oh43. They found no influence of the endosperm genotype on pericarp thickness. It was also observed that the sh2 mutant produced thicker pericarps than that of the + endosperm. This substantiates the possibility in this experiment that sh2 is linked with genes that produce thick pericarps, or somehow physiologically leads to thicker pericarps. Therefore, most super-sweet corn with the sh2 endosperm would have a tendency to have tough ears if this is true.

Helm and Zuber (1969, 1970) reported that B37 and Oh43 had average pericarp thicknesses of 160 and 75 microns respectively when evaluated over years and locations. These same inbreds averaged 102 and 60 microns respectively in the present study (similar data for B37 occurred in the generation mean analysis). This suggests that pericarp thicknesses of B37 and Oh43 in Hawaii seedstocks differ from that maintained at the University of Missouri.

1.5 CONCLUSIONS

Mass selection for tenderness was conducted on 'Hawaiian Super-sweet No. 9' by criteria of pericarp thickness measurements and bite-test scores. With the first cycle of selection, both pericarp thickness and bite-test data was taken on the same ear. A high correlation occurred between bite-test scores of a trained individual and pericarp thickness measurements, suggesting that either tests can predict the results of the other quite well. There were no effects of the maturity of the unpollinated ear on pericarp thickness. Evaluation of the cycles of selection by pericarp thickness indicated that substantial progress in selection for thin pericarps was made through selection by pericarp thickness whereas marginal progress for thin pericarps was made through selection by bite-testing. Further progress in selection for pericarp thickness by micrometry is highly probable since no plateau was evident. Upon evaluation of the cycles of selection by bite-testing, the opposite effect occurred. Greater progress was made in selection for lower bite-test scores by bite-testing while slight progress was made through pericarp thickness selection. One position on the pericarps of kernels on 'Hawaiian Super-sweet No. 9' needs to be measured in future selection experiments for pericarp thickness since no interaction was found between positions and cycles of selection.

A generation mean analysis of crosses between thin and thick pericarped inbred lines indicated that pericarp thickness is largely controlled by additive gene effects with some dominance effects in the direction of thinner pericarps. A narrow sense heritability estimate of 51% was

observed for pericarp thickness. An average number of 1 through 7 effective factors was found to control the inheritance of pericarp thickness. These conclusions indicate that selection for pericarp thickness can result in substantial progress. Evaluations of the + and su kernels from the F1 ears indicated that either endosperm genotypes may be used to evaluate pericarp thickness since pericarp thicknesses of these genotypes were identical.

Generally, the sweet corn hybrids grown at Waimanalo and at Lalamilo were similar in pericarp thickness. Ears evaluated at sweet corn stage were thinner in pericarp thickness than ears evaluated at maturity.

A survey of pericarp thicknesses on some of the races of maize indicated that a large store of genetic variation existed in the group of races analyzed. Pericarp thicknesses ranged from 35.8 to 124.4 microns. This pool of genetic variability could be exploited by breeders converting lines to a desired pericarp thickness. Some of the related races were of similar pericarp thicknesses whereas others were quite different suggesting that pericarp thickness is independent of morphological and physiological characteristics.

Assessments of pericarp thickness of the endosperm mutants indicated that the endosperm does not affect pericarp thickness. However, the sh2 mutant is suspected of being linked to thick pericarps.

CHAPTER TWO

2. ORGANOLEPTIC STUDIES OF FREEZE-DRIED 'HAWAIIAN SUPER-SWEET NO. 9'

2.1 INTRODUCTION

Lapple and Clark (1952a) listed many reasons for drying of food products in industrial operations. Several of these reasons suggest that 'Hawaiian Super-sweet No. 9' could have a marketing potential as a freeze-dried product. These reasons are: 1) to reduce freight charge for long distance shipments; 2) to ensure keeping quality during storage; 3) to facilitate handling in process equipment; and 4) to increase the market appeal and salable value of the product. Other reasons for the development of a dehydrated super-sweet corn product lies in the quality of the corn itself. 'Hawaiian Super-sweet No. 9' has a very high sucrose content because the bt gene blocks starch synthesis in the endosperm (Brewbaker, 1977). Brewbaker (1977) also reported that 'Hawaiian Super-sweet No. 9' was judged to be superior to all sweet corns and equal to or better than all super-sweet corns by sensory panels.

Freeze-drying of super-sweet corn was judged to be highly acceptable to people of developed and developing countries (Banafunzi, 1974). Ears with the bt gene as compared to ears with the su gene produced a highly acceptable freeze dried product. Therefore, although an expensive process, freeze-drying of 'Hawaiian Super-sweet No. 9' may result in the development of a profitable snack food commodity. The experiments in this chapter are an extension of the findings of Banafunzi (1974). The following treatments were investigated in this study: 1) blanching

versus no blanching; 2) maturity preferences; and 3) applications of increasing concentrations of brine solution to kernels prior to freeze-drying.

2.2 LITERATURE REVIEW

The effects of freeze-drying of sweet and super-sweet corn were studied by Banafunzi (1974). Four endosperm mutants (bt, bt2, sh2, and su were evaluated for quality by sensory panels who rated the product on a hedonic scale of 5. Two blanching treatments, blanching and no blanching, were applied to all of the genotypes. Blanching was done simply by boiling in water. The kernels were prepared for freeze-drying by removing them from the cob with a knife or by hand. After freezing, the kernels were transferred to a Virtis freeze-drier set at a vacuum of 0.1 $\pm$ 0.05mm Hg, shelf temperature of 140F, and left for about 16 hours.

Banafunzi (1974) reported that freeze-dried super-sweet corn was of higher quality than sweet corn regardless of the blanching treatment. Sweetness, however, was observed to diminish significantly in ears of the bt genotype. This was considered due to the leaching of sugars into the boiling water. However, the flavor of ears with the bt gene was enhanced by blanching. It was suggested that steam blanching could be used as the method of cooking to minimize the loss of sugars.

2.3 MATERIALS AND METHODS

2.3.1 Blanching Versus No Blanching

Banafunzi (1974) observed that there was a reduction of sweetness in freeze-dried super-sweet corn due to blanching. He also suggested that corn should be steamed rather than boiled to minimize the loss of flavor from the leaching of sugars into the boiling water. Unblanched kernels, however, would retain all of their sugars and should result in a sweeter freeze-dried product. Organoleptic investigations were conducted to decide whether blanched or unblanched kernels prior to freeze-drying would be judged as superior by sensory panels.

Samples of 'Hawaiian Super-sweet No. 9' ('HSS9') were harvested at prime sweet corn stage (approximately 20 days after pollination). On the same day of harvest, half of the ears were left unblanched and half were blanched by steaming. The blanching process was conducted by placing one layer of ears in the tray of a steamer with water already vigorously boiling. After steaming for about 12 minutes, the ears were immediately cooled by immersing them in coold water for about 5 minutes. The kernels were removed first by cutting out two rows of kernels from the ears and discarding them. Then the rest of the kernels were pushed off with the thumb. It was noted that kernels of unblanched ears and of ears (blanched or unblanched) with uneven rows were difficult to remove. These were cut off from the cob at the base with a sharp knife. The kernels were then placed in large sealed plastic bags and stored in a freezer. Prior to freezing, any free water was drained from the blanched kernels to prevent the kernels from being frozen solid

together making separation difficult at the time of freeze-drying.

After freezing, samples of both treatments were put into aluminum trays which were then put into a Virtis sublimator (Model-15) for 16 hours. The condenser temperature was set at -60C, the vacuum at 0.2 ± 0.05mm Hg, and the shelf temperature was set at 60C. The finished freeze-dried product was stored in large sealed plastic bags in a dehumidified room until evaluated by sensory panels.

2.3.2 Optimal Maturity for Freeze-drying of 'HSS9'

The next logical step towards perfecting the freeze-dried 'HSS9' product was to optimize the maturity of 'HSS9' as judged by sensory panels. A population of 'HSS9' was planted and the most vigorous plants were selected by visual appearance for controlled pollination. Ears were harvested at four different dates which were 18, 21, 25, and 28 days after pollination (DAP). Eighteen DAP was considered to be early sweet corn stage. After each harvest, measurements of dry matter content of the kernels were taken as a second measure of maturity. All ears were blanched prior to freeze-drying by the method described in Section 2.3.1.

2.3.3. Brined Freeze-dried 'HSS9'

Generally, most people consume corn whether on the cob or as cut kernels by adding salt and butter. Preliminary trials were conducted to assess these additions to the kernels prior to freeze-drying, i.e., after blanching and removal of the kernels (described in Section 2.3.1). Whether in combination with brine or not, buttering of the kernels

prior to freeze-drying produced an undesirably sticky freeze-dried product. Brining, on the other hand, did not produce any undesirable effects except the problem that the kernels possessed greater hygroscopic properties which would complicate storage. Preliminary concentrations of brine solution consisted of 0, 2, 4, 6, and 8% NaCl in water (weight of salt:volume of water). Panel members had difficulty in distinguishing these concentrations, therefore the concentrations were increased to 0, 3, 6, 9, and 12% NaCl in water. The water was heated to expedite the dissolving of the salt and to ensure uniform application of the brine solution on to the kernels. The brine solution was then poured over the kernels which were placed in a pan after blanching and removal from the cobs. The kernels were tossed around in the pan and left to stand for about 2 minutes after which the brine solution was drained completely. The remaining amount of salt on the kernels determined its desirability to the panel members. The freeze-drying procedure used was described in Section 2.3.1.

2.3.4 Evaluations of Eating Quality

All evaluations were conducted by a trained 10 member sensory panel from the Horticulture Department. Participants were trained in acquiring a taste for the freeze-dried product and on the method of multi-sample comparisons for eating quality. A hedonic scale of 7, which ranged from 7 (like very much) to 4 (neither like nor dislike) to 1 (dislike very much), was used to discriminate the quality of freeze-dried 'HSS9'. One experiment was evaluated on a single day. Days were considered as replications and were not necessarily consecutive. Comparisons of

appearance was made under ample light between blanched and unblanched freeze-dried kernels and among freeze-dried kernels from various harvest dates by placing the kernels on plates labeled with a random number. Eating quality for these treatments was assessed in booths equipped with a red light which eliminated any bias due to visual appearance. The brined kernels were not evaluated in booths since they were of similar appearance.

2.4 RESULTS AND DISCUSSION

Three consecutive experiments on 'Hawaiian Super-sweet No. 9' were conducted to perfect the methodology of freeze-drying super-sweet corn previously described by Banafunzi (1974). The best results of the previous experiments in this chapter were used to evaluate the product in the following experiments, i.e., blanching was found to be rated higher by sensory panels and therefore in the next experiments the kernels were blanched prior to freeze-drying. The three experiments conducted were: 1) blanching versus no blanching; 2) maturity preferences of the kernels; and 3) concentrations of salt in the brine solution.

2.4.1 Blanching Versus No Blanching Prior to Freeze-drying

The average scores of the sensory panelists for the blanching experiment are presented in Table 32. The mean values show that panelists generally had no preferences regarding the flavor of blanched or unblanched kernels prior to freeze drying. A score of 5 was interpreted as 'like slightly' while a score of 6 was interpreted as 'like moderately'. The means for appearance was 5 for blanched kernels and 3.5 (slightly dislike) for unblanched kernels suggesting that consumers would prefer the blanched freeze-dried kernels. There is a higher standard deviation for the unblanched treatment suggesting that the panelists were less sure, on a day to day basis, whether this process was desirable or not.

The analysis of variance for the means in Table 32 indicates that there was a 5% significant difference between the flavor of blanched

Table 32

Average scores of sensory panelist on blanched and unblanched 'Hawaiian Super-sweet prior to freeze-drying

Treatment	Flavor		Appearance	
	$\bar{x}$	s	$\bar{x}$	s
Blanched	5.8	0.86	4.9	1.56
Unblanched	5.3	1.87	3.5	2.00

Table 33

Analysis of variance for average scores between blanched and unblanched kernels of 'Hawaiian Supersweet No. 9' in Table 32

Source	df	Mean Square	
		Flavor	Appearance
Replication (R)	3	0.34	0.58
Panelist (P)	9	3.81*	5.93***
Error a	27	1.33	0.59
Treatment (T)	1	3.09*	16.51***
T X P	9	1.96	3.21
Error b	30	0.91	0.54

and unblanched kernels in the freeze-drying process (Table 33). However, highly significant differences were detected between their appearance. There was a highly significant interaction mean square between panelist and treatments, suggesting that panelists differed in their severity of judgement between the two treatments. Only one judge preferred the unblanched over the blanced product (Appendix--Table 46). Unblanched kernels were commented to have a pale yellow color like raw corn, whereas blanched kernels were brighter in color similar to cooked fresh corn. Blanched kernels were also commented to have a better taste and texture whereas the unblanched kernels were commented to be sweeter but of chalky texture. Since the appearance of blanched kernels were preferred, blanching of the kernels prior to freeze-drying was utilized for subsequent experiments.

2.4.2 Optimum Maturity for Freeze-dried 'HSS9'

Various harvest stages of the ears of 'Hawaiian Super-sweet No. 9' ('HSS9') were evaluated for their effect on the freeze-dried product. Generally, it is desirable to process the kernels at later stages of development for increased yield (in terms of dry matter) of the product. However, higher profits may be obtained if the palatability of the product were of high quality. Four dates of harvests were selected: 18, 21, 25, and 28 days after pollination (DAP). The average scores of sensory panelists on flavor and appearance of the product at different harvest dates are presented in Table 34. The means are similar at the harvest dates of 18, 25, and 28 DAP, while a slight decrease occurred at 21 DAP.

Table 34

Average scores of sensory panelists on various harvest stages of 'Hawaiian Super-sweet No. 9'

Maturity (Days After Pollination)	Percent Dry Matter	Flavor		Appearance	
		$\bar{x}$	s	$\bar{x}$	s
18	21.9	5.4	1.79	4.1	1.70
21	23.8	4.8	1.10	5.0	1.13
25	26.2	5.3	0.77	5.4	0.77
28	27.8	5.2	1.64	5.4	1.63

Table 35

Analysis of variance for average ratings of harvest stages between flavor and between appearance in Table 33

Source	df	Mean Squares	
		Flavor	Appearance
Replication	3	0.34	0.08
Panelists	9	3.81*	5.93***
Error a	27	1.33	0.59
Maturity	3	3.09*	16.51***
Maturity X Panelists	27	1.96	3.21***
Error b	90	0.91	0.54

The panelists commented that samples harvested at 18 DAP were desirable in their characteristic soft texture and sweetness, but at the same time the crunchiness of the kernels harvested at late sweet corn stage was also desirable. Kernels harvested at 28 DAP were overly crunchy but were similar in taste to kernels harvested at 25 DAP. The appearance of the kernels at 18 DAP was not as desirable as kernels at late harvest. There were light yellow, round, flakey, and hollowed in appearance. The hollowing was due to the fact that the kernels had to be cut out with a knife since pushing them off with the thumb resulted in crushed kernels. On the other hand, kernels at late harvest were large whole kernels that were rich in color. A large standard deviation was recorded for kernels harvested at 25 DAP indicating that this was consistently rated at a score of 5. Considering these factors, the most appropriate selection of maturity appears to be 25 DAP.

The mean square for flavor and appearance are presented in Table 35. The mean square for maturity was just barely significant when rated for flavor, but was highly significant when rated for appearance. There was a highly significant difference among panelists. There also was a highly significant maturity x panelists mean square indicating that the panelists differed in their severity in rating the different maturities.

2.4.3 Brined Freeze-dried 'HSS9'

Utilizing kernels from ears harvested at about 25 DAP, an experiment evaluating preferences of increasing concentrations of salt in brine solutions was conducted. The concentrations used were 0,3,6,9, and 12% salt in the brine solution. The mean scores of sensory panelists

Table 36

Average scores of sensory panelists on various concentrations of brine solution on freeze-dried 'Hawaiian Super-sweet No. 9'

Treatment (% Brine)	Flavor	
	$\bar{x}$	s
0	5.2	1.77
3	5.2	1.48
6	5.3	1.86
9	5.2	1.41
12	4.6	2.14

Table 37

Analysis of variance for average sensory panelists scores on the concentration of brine solution in Table 35

Source	df	Mean Square
Replication	3	0.70
Panelists	9	5.58***
Error a	27	0.51
Treatment	4	3.27*
Treatment X Panelists	36	3.16
Error b	120	1.32

on increasing concentrations of brine solution are presented in Table 36. The means indicate that there were no differences among the 0-9% treatment while a drop in the scores occurred for the 12% treatment. Judging from the means, this drop in the scores was responsible for the significance at the 5% level of the mean square for treatment in Table 37. There were significant differences among panelists but no significant interaction was found between treatments and panelists. This indicates that the panelists differed only in the severity of the ratings within a treatment but not between treatments. Therefore, it was concluded that 0-9% brine solution applied to the kernels prior to freeze-drying are equally acceptable to the sensory panelists. No specific brine treatment of the kernels is recommended in marketing a freeze-dried 'Hawaiian Super-sweet No. 9' product. This would also eliminate hygroscopic properties of the kernels thus sustaining shelf life.

2.5 CONCLUSIONS

'Hawaiian Super-sweet No. 9' as a freeze-dried product was rated as an acceptable but not outstandingly acceptable product as was indicated by scores ranging between 5 and 6. However, it may be salable in the market as most of the panelists indicated that they would purchase the product if it were reasonably priced in the markets. This price has not been decided as no data was taken to evaluate the cost of production for this product.

Blanched kernels were found to be similar to unblanched kernels in terms of flavor, however due to their higher ratings in appearance, blanching was selected as the method of preparation of kernels prior to freeze-drying. A harvest date of 25 days after pollination was selected as the optimum maturity primarily due to visual appearance. Brining of the kernels at 25 days after pollination at various concentrations indicated no significant preference between no treatment and 3-9% brine solutions, therefore, no brine treatment should be best applied to the final freeze-dried product.

APPENDIX

Appendix Table 38

Mean pericarp thickness for each plot in the selection experiment for tenderness in 'Hawaiian Super-sweet No. 9'

Reps	C0	P1	P2	P3	B1	B2	B3	B4	Average
1	72.2	65.9	65.4	52.6	62.6	75.6	61.9	55.1	63.9
2	75.8	72.4	68.7	55.6	71.5	74.2	71.6	74.6	70.4
3	75.2	88.0	67.2	53.2	80.1	70.0	73.1	70.7	72.3
4	67.5	71.1	57.1	53.3	67.3	71.8	57.3	61.5	64.8
5	76.0	67.5	56.1	54.3	67.5	73.3	65.4	64.5	65.1
6	65.5	66.6	64.2	50.7	73.7	65.4	61.5	70.3	65.0
7	77.4	73.9	63.7	57.8	76.4	67.8	78.9	69.3	69.9
8	76.0	64.8	57.5	56.9	69.8	71.8	65.3	65.3	65.5
9	70.4	64.7	61.6	50.2	72.0	77.1	76.2	66.7	66.6
10	80.4	61.2	57.9	49.4	68.2	77.6	66.9	63.6	64.5
Average	73.7	69.9	61.8	53.3	70.9	72.2	69.0	66.2	

Appendix Table 39

Mean bite-test score for each plot in the selection experiment for tenderness in 'Hawaiian Super-sweet No. 9'

Reps	C0	P1	P2	P3	B1	B2	B3	B4	Average
1	2.60	3.10	3.15	3.40	3.50	3.00	2.50	2.20	2.94
2	3.33	3.20	2.85	2.55	2.27	2.17	2.50	2.33	2.66
3	3.25	2.90	2.80	3.35	3.32	2.25	2.50	2.23	2.82
4	3.35	2.95	3.05	2.90	2.95	2.05	2.67	2.80	2.85
5	3.12	3.23	2.50	2.95	2.55	2.12	2.40	2.40	2.70
6	3.33	2.82	2.95	2.17	2.90	2.15	2.30	2.30	2.63
7	2.90	2.62	3.05	2.72	2.00	2.95	2.70	2.70	2.62
8	3.10	3.36	2.45	2.33	2.45	3.20	2.85	2.85	2.83
9	2.95	2.70	3.09	2.62	2.90	3.15	2.92	2.92	2.85
10	2.00	2.75	2.80	1.75	3.11	2.50	2.65	2.50	2.52
Average	2.98	2.97	2.87	2.72	2.78	2.56	2.51	2.51	

Appendix Table 40

Statistics of dispersion for pericarp thickness in microns for major sweet corn hybrids (mature stage) in the U.S. grown at Lalamilo

	Hybrids	$\bar{x}$[a]	s	$s_{\bar{x}}$	C.V.	n[b]
	Stylepak	31.2	10.85	1.53	34.79	50
	Jubilee	37.2	4.69	0.66	12.60	50
	Iobelle	35.8	8.91	1.55	24.89	33
	Sweet Sue	37.7	5.20	0.82	13.79	40
Germinal	GCB (N)	39.6	7.15	1.01	18.07	50
(top)	GCB (T)	36.7	5.64	0.88	15.39	41
	NK51036	41.5	5.80	0.92	13.98	40
	H68	37.8	6.36	0.90	16.81	50
	Bonanza	43.5	10.39	1.47	23.86	50
	Midway	49.8	12.12	1.72	24.36	50
	Gold winner	50.1	7.94	1.25	15.84	40
	Stylepak	33.7	14.34	2.03	42.59	50
	Jubilee	38.8	5.43	0.76	14.01	50
	Iobelle	38.6	12.09	2.10	31.30	33
	Sweet Sue	42.5	8.48	1.34	19.92	40
Germinal	GCB (N)	41.7	6.72	0.95	16.13	41
(bottom)	GCB (T)	40.3	7.20	1.12	17.86	40
	NK51036	42.0	6.16	0.97	14.66	50
	H68	50.1	7.09	1.00	14.15	50
	Bonanza	45.8	10.24	1.45	22.37	50
	Midway	54.9	10.45	1.48	19.04	50
	Gold Winner	58.4	8.35	1.32	14.31	40
	Stylepak	37.5	9.08	1.28	24.23	50
	Jubilee	44.5	10.03	1.42	22.55	50
	Iobelle	46.4	8.37	1.46	18.04	33
	Sweet Sue	43.9	10.02	1.58	22.82	40
Abgerminal	GCB (N)	50.2	12.10	1.71	24.09	41
(bottom)	GCB (T)	52.6	9.41	1.47	17.89	40
	NK51036	48.5	6.50	1.03	13.41	50
	H68	53.6	10.42	1.47	19.45	50
	Bonanza	50.8	13.14	1.86	25.87	50
	Midway	56.9	9.99	1.41	17.56	50
	Gold Winner	60.2	8.16	1.29	13.56	40

Appendix Table 40. (continued) Statistics of dispersion for pericarp thickness in microns for major sweet corn hybrids (mature stage) in the U.S. grown at Lalamilo

	Hybrids	$\bar{x}$	s	$s_{\bar{x}}$	C.V.	n
Abgerminal (top)	Stylepak	36.8	10.86	1.54	29.54	50
	Jubilee	35.7	3.26	0.46	9.14	50
	Iobelle	40.0	8.95	1.56	22.40	33
	Sweet Sue	41.0	10.27	1.62	25.07	40
	GCB (N)	38.8	5.91	0.84	15.52	50
	GCB (T)	42.1	7.15	1.12	16.96	41
	NK51036	45.4	7.16	1.12	15.78	40
	H68	36.6	5.59	0.79	15.25	50
	Bonanza	46.8	12.18	1.72	26.06	50
	Midway	42.8	9.80	1.39	22.89	50
	Gold Winner	52.8	13.43	2.12	25.44	40
Average	Stylepak	34.8a	11.59	0.82	33.33	200
	Jubilee	39.0ab	7.15	0.51	18.30	200
	Iobelle	40.2ab	10.37	0.90	25.80	132
	Sweet Sue	41.3bc	8.96	0.71	21.69	160
	GCB (N)	42.4bc	9.52	0.67	22.45	200
	GCB (T)	42.9bc	9.50	0.74	22.12	164
	NK51036	44.4bc	6.97	0.55	15.72	160
	H68	44.5bc	10.58	0.75	23.76	200
	Bonanza	46.7cd	11.75	0.83	22.15	200
	Midway	51.1d	11.88	0.84	23.25	200
	Gold Winner	55.4d	10.50	0.83	18.96	160

[a] Mean separation in Average row by Duncan's BLSD, 5% level (BLSD = 6.43)

[b] n represents the number of data points entering the mean. A close approximation of the number of ears for each hybrid is n in the Average row divided by 20

Appendix Table 41

Analysis of variance for pericarp thickness in microns for the major sweet corn hybrids (mature stage) at Lalamilo in Appendix Table 40

Source	df	Mean Square
Positions	3	9308.6***
Replication	1	565.0
Error a	3	151.3
Hybrids	10	5701.9***
Hybrids X Position	30	430.6
Error b	40	1027.3
Sampling Error	320	203.4***
Subsampling Error	1608	32.5

Appendix Table 42. -- Statistics of dispersion for pericarp thickness in microns for major sweet corn hybrids (sweet corn stage) in the U.S. grown at Waimanalo

	Hybrids	$\bar{x}$ [a]	s	$s_{\bar{x}}$	C.V.	n
Germinal	Jubilee	33.1	6.14	1.11	19.13	50
	Iobelle	28.6	4.60	0.87	16.07	50
	Sweet Sue	32.5	7.99	1.34	24.60	50
	Bonanza	33.9	6.26	1.13	18.47	50
	Silver Queen	34.7	9.88	1.50	28.48	50
	Stylepak	37.0	10.62	0.65	28.66	50
	GCB (N)	38.3	7.97	1.02	20.82	50
	NK51036	43.1	6.84	1.23	15.89	45
	GCB (T)	41.7	8.42	1.40	20.18	50
	H68	40.9	7.83	1.19	19.13	50
	Gold Winner	45.9	8.71	1.13	18.99	50
	Midway	45.8	9.98	0.88	19.62	45
Abgerminal	Jubilee	36.7	8.62	1.48	23.49	50
	Iobelle	44.4	5.09	1.22	11.46	50
	Sweet Sue	41.4	6.90	1.45	16.66	50
	Bonanza	41.1	7.91	0.97	19.26	50
	Silver Queen	44.1	8.82	1.46	19.97	50
	Stylepak	46.6	10.35	0.72	22.21	50
	GCB (N)	46.6	10.60	1.44	22.74	50
	NK51036	47.4	9.66	1.28	20.35	45
	GCB (T)	51.4	8.20	1.25	15.96	50
	H68	53.9	10.44	1.16	19.38	50
	Gold Winner	51.4	9.07	1.50	17.66	50
	Midway	53.5	9.70	1.12	18.13	45
Average	Jubilee	34.9a	7.66	1.12	21.96	100
	Iobelle	36.5a	9.29	0.77	25.43	100
	Sweet Sue	36.9a	8.68	1.01	23.51	100
	Bonanza	37.5ab	7.96	0.87	21.23	100
	Silver Queen	39.4abc	10.46	1.15	26.52	100
	Stylepak	41.8abcd	11.48	0.93	27.45	100
	GCB (N)	42.4abcd	10.23	0.86	24.09	100
	NK51036	45.3bcd	8.61	0.93	19.02	90
	GCB (T)	46.5cd	9.59	1.05	20.60	100
	H68	47.4cd	11.25	0.96	23.72	100
	Gold Winner	48.6d	9.27	1.03	19.07	100
	Midway	49.6d	10.07	0.80	20.30	90

[a] Mean separation in Average row by Duncan's BLSD, 5% level (BLSD = 8.75)

Appendix Table 43. -- Analysis of variance for pericarp thickness for the major sweet corn hybrids (sweet corn stage) at Waimanalo in Appendix Table 42

Source	df	Mean Square
Positions	1	21963.0***
Replication	1	1375.0
Error a	1	611.0
Hybrids	11	2625.1***
Hybrids X Positions	11	288.4
Error b	22	238.3
Sampling Error	188	243.7***
Subsampling Error	944	31.7

Appendix Table 44. -- Statistics of dispersion for pericarp thickness in microns for major sweet corn hybrids (mature stage) in the U.S. grown at Waimanalo

	Hybrids	$\bar{x}$ [a]	s	$s_{\bar{x}}$	C.V.	n
	Jubilee	40.7	6.78	0.69	16.64	96
	Bonanza	42.1	5.65	0.58	13.41	94
	Stylepak	41.5	8.40	0.75	20.24	94
	H68	44.0	9.22	0.98	20.94	88
	NK51036	47.1	6.89	0.73	14.64	88
Germinal	Silver Queen	47.3	6.39	0.64	13.52	100
	GCB (N)	50.6	8.24	0.85	16.29	94
	GCB (T)	53.8	6.52	0.65	12.12	100
	Iobelle	53.2	8.51	0.86	16.00	97
	Midway	52.7	8.68	0.87	16.46	100
	Gold Winner	52.6	5.87	0.59	11.16	99
	Jubilee	43.1	6.17	0.63	14.31	96
	Bonanza	45.4	7,56	0.78	16.68	94
	Stylepak	47.6	10.56	1.09	22.16	94
	H68	54.6	17.39	1.85	31.82	88
	NK51036	53.8	7.71	0.82	14.34	88
Abgerminal	Silver Queen	59.7	7.35	0.74	12.33	100
	GCB (N)	58.3	7.97	0.82	13.67	94
	GCB (T)	56.1	7.13	0.71	12.70	100
	Iobelle	57.0	10.60	1.08	18.60	97
	Midway	62.2	9.39	0.94	15.11	100
	Gold Winner	64.0	8.27	0.83	12.93	99
	Jubilee	41.9a	6.58	0.48	15.68	192
	Bonanza	43.8ab	6.85	0.50	15.66	188
	Stylepak	44.6abc	10.00	0.73	22.43	188
	H68	49.3bcd	14.86	1.12	30.12	176
	NK51036	50.4cd	8.03	0.61	15.93	176
Average	Silver Queen	53.5de	9.27	0.66	17.34	200
	GCB (N)	54.4de	8.95	0.65	16.45	188
	GCB (T)	54.9de	6.91	0.49	12.58	200
	Iobelle	55.1de	9.78	0.70	17.75	194
	Midway	57.4e	10.19	0.72	17.73	200
	Gold Winner	58.3e	9.15	0.65	15.70	198

[a] Mean separation in Average row by Duncan's BLSD, 5% level (BLSD = 6.16)

Appendix Table 45. -- Analysis of variance for pericarp thickness in microns for the major sweet corn hybrids (mature stage) at Waimanalo in Appendix Table 44

Source	df	Mean Square
Replication	1	1302.0
Hybrids	10	6230.2***
Positions	1	25209.0***
Hybrids X Positions	10	659.0
Experimental Error	21	972.7***
Sampling Error	384	214.5***
Subsampling Error	1672	28.1

Appendix Table 46

Scores of 10 panelists for the appearance of blanched and unblanched freeze-dried 'Hawaiian Super-sweet No. 9'

Treatment	Reps[a]	Panelists									
		1	2	3	4	5	6	7	8	9	10
Blanched	1	6	7	5	6	4	5	3	6	7	5
	2	6	6	6	5	4	5	4	5	3	6
	3	6	6	5	6	3	5	2	5	5	5
	4	6	3	5	6	4	4	2	5	4	6
Unblanched	1	7	3	1	5	3	3	6	3	6	4
	2	6	1	2	4	3	3	4	3	4	6
	3	6	4	1	4	2	2	5	3	5	5
	4	3	3	2	3	3	3	5	5	5	5

[a] Reps = Days treated as replication

Appendix Table 47

Scores of 10 panelists for the flavor of blanched and unblanched freeze-dried 'Hawaiian Super-sweet No. 9'

Treatment	Reps	Panelists									
		1	2	3	4	5	6	7	8	9	10
Blanched	1	5	3	7	6	6	5	5	6	7	6
	2	7	4	6	6	6	5	6	7	6	6
	3	4	6	7	6	6	6	4	6	6	6
	4	7	6	5	6	5	5	7	5	6	6
Unblanched	1	7	2	7	5	5	6	7	5	4	3
	2	6	7	7	5	5	7	5	7	4	7
	3	6	3	6	4	4	7	3	5	5	5
	4	6	3	6	5	5	6	5	7	4	5

Appendix Table 48

Percentage of dry matter for maturity of 'Hawaiian Super-sweet No. 9' defined as days after pollination

Ear Number	Days After Pollination (% dry matter)			
	18	21	25	28
1	21.0	23.4	24.7	30.2
2	22.2	21.4	26.0	27.2
3	22.3	23.0	26.4	27.7
4	24.7	22.4	26.1	28.0
5	22.5	23.6	26.4	25.9
6	20.4	23.0	25.3	27.4
7	23.3	24.7	26.1	29.0
8	21.0	23.9	28.8	26.0
9	21.4	25.2	27.5	28.4
10	20.6	27.3	24.6	27.5
x	21.9	23.8	26.2	27.8
s	1.26	1.64	1.26	1.36
C.V.	5.78	6.89	4.81	4.89

Appendix Table 49

Analysis of variance for maturity in Appendix Table 48

Source	df	Mean Square
Maturity	3	66.12***
Error	36	1.98

Appendix Table 50

Scores of 10 panelists for flavor of freeze-dried 'Hawaiian Super-sweet No. 9' at different dates of harvests

		Panelists									
DAP	Reps	1	2	3	4	5	6	7	8	9	10
18	1	7	6	6	6	6	6	2	5	7	5
	2	4	4	6	6	5	7	6	3	5	7
	3	5	6	7	4	4	6	3	5	5	6
	4	7	7	6	7	4	6	4	3	6	7
21	1	6	4	6	4	5	5	6	6	4	3
	2	6	4	6	6	6	6	5	5	6	3
	3	6	4	6	4	4	4	5	5	5	6
	4	5	4	5	6	4	4	3	3	4	5
25	1	4	6	5	5	4	5	7	5	5	6
	2	6	5	6	6	5	6	6	5	5	5
	3	5	3	6	4	5	5	7	4	4	5
	4	6	5	5	6	6	5	7	4	4	5
28	1	6	6	5	4	4	5	7	6	6	5
	2	6	2	5	5	7	6	7	4	4	5
	3	6	3	6	5	7	5	6	4	4	5
	4	6	3	7	6	4	5	6	3	3	5

[a] DAP = Days after pollination

Appendix Table 51

Scores of 10 panelists for appearance of freeze-dried 'Hawaiian Super-sweet No. 9' at different dates of harvests

		Panelists									
DAP	Reps	1	2	3	4	5	6	7	8	9	10
18	1	4	7	2	5	3	5	3	5	4	4
	2	5	7	3	5	3	5	4	3	4	5
	3	4	6	2	5	3	5	2	5	3	3
	4	4	7	2	4	3	4	3	4	4	4
21	1	5	3	7	6	4	6	4	5	5	6
	2	5	3	4	6	4	6	5	5	5	5
	3	4	7	6	6	4	6	4	4	4	5
	4	4	7	5	6	4	5	3	5	5	6
25	1	6	6	5	6	4	6	4	6	6	5
	2	6	6	6	6	6	5	5	5	5	3
	3	7	4	6	7	5	5	4	6	6	6
	4	6	6	6	6	5	5	4	5	5	6
28	1	6	4	5	6	5	6	4	7	7	3
	2	6	4	7	6	5	6	5	7	6	3
	3	7	4	7	7	6	6	4	6	6	3
	4	6	4	6	6	6	5	4	7	6	3

Appendix Table 52

Scores of 10 panelists for the flavor of freeze-dried 'Hawaiian Supersweet No. 9' with increasing concentrations of brine

% Brine Solution	Reps	Panelists									
		1	2	3	4	5	6	7	8	9	10
0	1	6	4	3	7	7	6	5	2	6	3
	2	5	5	3	5	6	4	4	4	5	4
	3	6	6	7	7	6	6	7	3	6	5
	4	6	5	6	7	6	5	4	5	7	5
3	1	7	6	5	5	5	5	6	5	3	5
	2	6	4	3	3	7	6	7	6	4	5
	3	5	6	3	3	5	6	6	6	4	3
	4	6	6	6	6	5	6	5	6	4	3
6	1	7	5	7	7	5	3	4	3	7	3
	2	6	6	7	7	6	7	6	4	7	5
	3	5	6	4	4	5	5	4	5	7	4
	4	4	6	7	7	4	5	5	4	3	4
9	1	5	6	6	6	6	7	6	6	3	5
	2	4	7	6	6	6	4	4	6	5	5
	3	4	7	5	5	5	5	5	6	3	6
	4	5	5	3	3	5	6	6	6	2	6
12	1	6	7	5	5	6	6	3	6	2	4
	2	5	6	5	5	5	5	3	3	4	3
	3	6	5	5	5	7	4	3	3	2	5
	4	5	7	6	6	7	4	4	3	2	5

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